Investigation of the Mercury Arc Rectifier by Means Of the Oscillograph

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INTRODUCTION.

A considerable field of usefulness exists for a compact and reliable apparatus for converting alternating current into continuous on a small scale, especially for charging accumulators. Neither the motor generator nor the rotary converter is in the immediate future likely to be superseded for the conversion of large powers at comparatively low potentials from alternating to direct current, but for smaller powers there are now two systems of rectification in commercial operation, both of them having the supreme advantage of no moving parts,-viz., the electrolytic rectifier, and the mercury arc rectifier.

The Electrolytic Rectifier.

The chemical rectifier is only serviceable for short runs. It has never been developed to any degree of efficiency and has never been a very satisfactory piece of apparatus.

The Mercury Arc Rectifier.

It will be the object of this thesis to study the mercury arc rectifier, its uses, limitations, advantages, disadvantages, and characteristics under various conditions by means of the oscillograph.

Before the introduction of the mercury arc rectifier the rectification of alternating current was only possible by means of the motor generator set, rotary converter, synchronous or mechanically driven rectifiers, and chemical rectifiers. Obviously all the foregoing arrangements,

except the electrolytic rectifier, necessitate moving parts that are subject to wear and hence need frequent adjustments and renewals, have lower efficiency, besides being expensive to install. An attendant who has had some experience with electrical appliances must also be provided and this further adds to the operating expense. For these reasons there has existed for a long time a demand for a cheap device for rectifying or converting alternating into continuous current, that should at once be compact, efficient, and not apt to get out of order. The General Electric Company's Mercury arc rectifier shown in Plate II fulfills these conditions to a nicety since it is lower in first cost, higher in efficiency, more compact and more simple to operate than any mechanical converter. It requires practically no attention and for charging batteries it is almost ideal.

The General Electric Company's mercury arc rectifier with a 20 ampere, 100 volt tube was used on a single phase line throughout this test.

The investigation of this rectifier was taken up under the following heads; study of the theory and operation; experimental determination of the characteristics under varying conditions of impressed E.M.F., rectified E.M.F., frequency, load, reactance and varying wave forms; and the explanation of the results by means of the oscillograph.

DESCRIPTION.

The Single-Phase Mercury Arc Rectifier equipment, a front and side view of which is shown in Plate III, consists of a slate panel, 40" x 16" x $1\frac{1}{2}$", rigidly held in position by pipe supports, and to which the following parts are connected:

1 Double pole circuit breaker
1 Ammeter
1 Voltmeter
1 A.C. line switch
1 Rectifier tube
1 Rectifier tube holder
1 Starting switch
1 Combined starting and starting anode resistance.
1 Regulating reactance and controlling switch
1 Compensating reactance and dial switch.

The compensating reactance and dial switch is placed directly below the panel.

TUBE.

The tube is an elongated, cylindrical, exhausted glass vessel, having two anodes, A-A'(See Plate V, Fig. 1), one cathode, B, and a starting anode, C. The tubes differ in size according to their ampere capacity, and in shape according to the D. C. voltage at which they are to be used. Tubes should never be used above their rated voltage. If used at lower voltage they may sometimes be hard to start but otherwise will be satisfactory.

The tube must be very highly exhausted in order to insure its rapid starting. The presence of foreign gases or inert mercury vapor impedes the starting. It is comparatively easy to produce a vacuum in the tube but a difficult matter to completely drive out gases that are absorbed in

the walls of the tube and the anode material. Since the vacuo of the tube becomes impaired with use great care must be used to attain as nearly a perfect vacuum as is possible in the first place.

The shape of the tube must be such as to allow the free flow of cathodic ions to the anode. Capillary or bent tubes hinder or prevent the starting of the main arc and are therefore avoided.

The tube used in this test was of a 20 ampere capacity. There is theoretically no limit to the capacity of the tube, but in practice the difficulties of introducing large currents into an exhausted glass vessel and of dissipating the energy wasted in the form of heat in the rectifier itself are to be met. These difficulties have been sufficiently overcome to build a tuble of 100 amperes capacity.

The tube must also be of sufficient size to provide ample condensing space. The conductivity of the arc depends on the relative amounts of ionized and inert mercury vapor; hence the necessity for condensation. Sufficient space must also be provided to keep down the pressure of the ordinary mercury vapor volatilized from the cathode to a certain value so that conductivity of the arc is almost exactly proportioned to the current.

The anodes are not made of mercury for the reason that they would result in inert mercury production.

HOLDER.

The tube holder, mounted on a support back of the panel, consists of an upper clip and a lower support for

holding the rectifier proper.

The holder is rigidly connected to a small hand wheel on the front of the panel, used to tilt the tube when starting. The support for the holder has four leads which make contact with the four terminals of the tube.

STARTING SWITCH.

The starting switch is a single-pole, double throw spring switch. It automatically transfers the rectified current from the starting resistance to the load. In charging storage cells the counter E.M.F. of resistance afforded by these cells is too great to permit the rectifier to start and hence a smaller resistance is used upon which to start the rectifier.

STARTING LOAD AND STARTING ANODE RESISTANCE.

These resistances are the enclosed card type and are mounted together on the back of the panel. The one serves as a starting load and the other limits the current in the starting anode, which would otherwise be excessive at the start when the two mercury services are brought into contact.

CONTROLLING REACTANCE.

The controlling reactance is connected in series in the A.C. line and is used to regulate the A.C. voltage supplied to the tube and thereby regulate the D.C. voltage while the rectifier is in operation.

COMPENSATING REACTANCE.

The compensating reactance is connected directly

across the alternating current supply, and is divided into several steps. The leads from these steps are internally connected to the dial switch, thus furnishing a convenient means of changing the A.C. Voltage and A.C. current supply. The compensating reactance is used to make the variation in A.C. voltage and A.C. current supply in graded steps. The controlling reactance performs a similar function but gives the finer adjustment.

AMMETER AND VOLTMETER.

The ammeter and voltmeter are of the inclined coil type since the rectified current is of a pulsating nature.

METHOD OF OPERATION

Adjust the circuit breaker to the desired maximum load, using care not to adjust it so as to exceed the capacity of the tube, and then close it.

Turn in the A.C. reactance, close the A.C. line switch, and hold the spring switch in the lower position. Rock the tube gently by means of the hand-wheel connected to the holder. This will cause a mercury bridge to be formed and broken between the starting anode, C, and the cathode, B. This in turn will cause a light flash and the rectifier will start. A single flash should be sufficient to start the tube, but in cold weather more may be necessary. When the hand is removed from the starting switch, the spring will throw the switch up, transferring the rectified current from the starting resistance to the load. If the voltage of the batteries being charged is higher than that of the rectifier, the tube will go out when the starting switch moves to the load position. The controlling reactance should then be cut partially out and the tube restarted. In case this will not give the current, the voltage should be further increased by means of the compensating reactance until the desired current and voltage is obtained. After the correct position of the dial switch is once determined it will not be necessary to change it again, since the regulation of the current may be obtained by the controlling reactance.

In starting up the rectifier on battery load, the

hand-wheel of the controlling reactance should be turned to the right, and after the rectifier has started should be turned back to such position as will give desired charging current. As the battery voltage rises, more reactance should be cut out until the heavy part of the charge is finished. The current should then be lowered by turning the handwheel to the right to give the proper finishing charge.

When the line voltage is comparartively free from fluctuations, the compensating reactance should be adjusted to give such voltage as to require a minimum use of the controlling reactance. If the line fluctuations are excessive and cause the rectifier to go out occasionally, it is advisable to use the maximum amount of this reactance; this will give greatly increased stability to the rectifier.

From General Electric Company's Instruction Book.

THEORY.

It will now be attempted to give a simple physical explanation of the action of the rectifier.

The rectifier consists broadly of a mercury vapor arc, enclosed in an exhausted vessel. Mercury vapor has a very great resistance to the passage of an electric current. For instance, if mercury is vaporized by the application of heat and the resistance of the vapor measured, this resistance will be found to be extremely high regardless of polarity. It is then obvious that a very high voltage would be necessary to pass current between two terminals placed in this vapor; in fact ordinary mercury vapor may be considered practically a non-conductor.

If, however, the mercury vapor is in some manner ionized, it becomes a good conductor but in one direction only. By ionizing the vapor is meant producing an electrolytic action by virtue of which mercury ions will be shot from a mercury electrode used as a cathode. When a mercury electrode is used as a cathode, ionized mercury vapor is liberated, hence the use in a mercury vapor lamp of a negative mercury electrode, the positive terminal being mercury or some other suitable material. When a negative mercury electrode is in an active state, as, for instance, when an arc is operating, only a few volts are necessary to sustain the arc in one direction, but the voltage must be extremely high to sustain an arc of reversed polarity; then the ionized vapor is a good conductor of current in one

direction, but, similar to ordinary mercury vapor, is an insulator in the opposite direction.

This action is taken advantage of in the mercury arc rectifier when the two anodes connected across the terminals of the alternating current line become alternately positive and negative. While either anode is positive, there is an arc carrying the current between it and the cathode, the cathode being negative. When the polarity of the alternating current line reverses, the arc passes from the other anode to the cathode, the cathode being still negative. Hence, during the complete cycle, the cathode is negative and the current at this point must be unidirectional.

It should be noted that the rectifier is so designed that the entire alternating current wave is used. This, of course, means that the rectifier has twice the efficiency that would be obtained if only one-half of the alternating-current wave were used. The use of the entire alternating current wave is clearly shown in the oscillograph records shown in Plate XX, Figs. 4 and 5. The upper curve shows the current in one anode; the lower curve, the simultaneous current in the other anode.

If it were possible to maintain the arc in a single-phase rectifier without auxiliary apparatus, the above discussion indicates that the resulting direct-current wave would be a pulsating wave of the same characteristics as the alternating-current wave from which it was derived, except that the current would vary from zero to a positive

maximum, the negative wave having been reversed so that it appears as positive to the zero line. Such a method of operation is impossible, because although the current is at zero for an infinitesimally short time, yet this interval of time is sufficient for the cathode to lose its excitation and the arc to go out. No matter how high a frequency is used, the arc will go out at the zero value of the wave.

By means of suitable reactances. the current is held over the zero value and the pulsations are smoothed out, the current of the cathode becoming not only uni-directional, but a true direct current with pulsations of small amplitude.

The resulting direct current is shown in Plate XXII. which is the result of superimposing the two curves shown in Plate XX, Figs. 4 and 5. The action of the reactance can be seen from Plate XX, Figs. 4 and 5, by carefully observing that the wave shape is evidently no longer a sine wave, but that durin its operation the reactance is sustaining the current at a higher value than it naturally would be; also that the current curves in each anode overlap by an angle of about 20 degrees, thus eliminating the zero points previously mentioned.

The cathode is then one terminal of the direct-current circuit. The junction between two reactance coils, such as referred to above, connected between the anodes, furnished the other terminal, so that any instant the circuit from the alternating-current line is composed of a rectifier arc, the load and one of the reactance coils. The other coil

is at the same time discharging the energy stored up during the previous half wave, at which time it was in the line circuit.

The initial ionization of the mercury vapor is accomplished by a small starting anode, C (see Plate 5, Fig. 2) which is brought into contact with the cathode by a mercury bridge formed by a slight shake of the tube. The breaking of this mercury bridge starts a small initial arc. and the arc thus obtained excites the cathode, giving the necessary ionized vapor, which enables the working anodes to become immediately active and the tube to start.

A detailed idea of the operation of the mercury arc rectifier circuit may be obtained from Plate 5, Fig. 2. Assume an instant when the terminal, H, of the supply transformer is positive, the anode A is then positive, and the arc is free to flow between A and B, B being the mercury cathode. Following the directions of the arrows, without the circles still further, the current passes through the load J, through the reactance coil E and back to the negative terminal G on the transformer. A little later, when the impressed E.M.F. falls below a value sufficient to maintain the arc against the counter E.M.F. of the arc and load, the reactance E, which heretofore has been charging, now discharges, the discharge current being in the same direction as formerly. This serves to maintain the arc in the rectifier until the E.M.F. of the supply has passed through zero, reverses and builds up to such a value as to cause A' to have a sufficiently positive value to start an arc between it and the mercury cathode B. The

discharge circuit of the reactance coil E is now through the arc A'B, instead of through its former circuit. Consequently the arc A'B is now supplied with current, partly from the transformer and partly from the reactance coil E. The new circuit from the transformer is indicated by the arrows enclosed in circles.

The charge and discharge voltage of one reactance coil is clearly shown in Plate XI, Fig. 3 By adjusting the amount of reactance inserted in the circuit the pulsations of the direct current can be made suitable for commercial purposes.

When it is advisable to reduce still further the amplitude of the pulsations, it may be accomplished by means of the reactances.

METHOD OF INVESTIGATION.

The object of the experimental part of this thesis is the study of the action, operation, characteristics and a visual study of E.M.F., current wave forms and vector relations in various circuits of the mercury arc rectifier by means of the oscillograph. The 100 volt, 20 ampere, D.C. 220 volt A.C. 60 cycle mercury arc rectifier number #7376 manufactured by the General Electric Company was used.

The E.M.F. was generated at 1100 volts and transformed to 220 or, if desired, to 110 by merely changing the connections at the transformer. The scheme for measurements on both the alternating and direct current sides of the rectifier are shown in Plate VI. The following instruments were used; on the alternating current side a voltmeter, ammeter, frequency meter and wattmeter. On the direct current side there was a direct current ammeter and voltmeter, an alternating current ammeter and voltmeter and a wattmeter. By means of a double pole double throw switch the A.C. voltmeter was used to measure the E.M.F. impressed at the anodes of the rectifier tube.

Since the rectified E.M.F. is pulsating readings were taken on both the alternating and direct current voltmeters in order to determine the relation of the effective and average of this E.M.F. from minimum to full load.

All the load characteristics such regulation, efficiency, apparent efficiency and power factor were

determined by varying the load throughout the limits of the tube and taking readings of alternating current volts, amperes, watts and direct current volts, amperes and watts. These characteristics were found for varying conditions of impressed E.M.F., such as wave form and frequency, also with incandescent lamps, arc lamps and motor loads.

In order to determine the alternating and direct current voltage relations of the rectifier tube the line was adjusted to 220 volts and the compensating reactance connected J-6, H-12 with the dial switch on 1 and 7 as explained in Plate IV. Readings were taken of A.C. and D. C. watts and volts with a constant load and the dial switch at 1-7, 2-8, 3-9, 4-10, 5-11, 6-12. The line connections to the reactance were changed to J-1, H-7 and another series of readings taken. This gives the lowest voltage with an impressed E.M.F. of 220, so the line was connected to give 110 volts and the compensating reactance back to J-6. H-12, and the same operation repeated until the minimum voltage of the rectifier was reached. With 110 volts A.C. the D.C. range is from 15 to 140 volts, and with 220 volts A.C. the range is from 45 to 115 volts. These voltage comparisons were made for different loads, wave forms and frequency. The efficiency was calculated for all connections of the compensating reactance, showing the most economical point of operation.

Plate XXIV shows the connection for measuring the drop over various parts and the current in all circuits of the rectifier.

TABLE I.

Westinghouse Alternator. [illegible] Wave.

Impressed Voltage-220. Frequency-60 cycles.

Edc	I_{dc}	I_{ac}	W_{dc}	W_{ac}	Efficiency	Apparent Efficiency	Power Factor
99.70	21.65	14.55	1525	2650	57.50	48.00	.840
9[illegible].70	20.80	12.75	1590	2500	55.60	46.00	.826
100.75	19.85	1[illegible].35	1590	2440	57.00	47.30	.830
102.75	18.00	11.75	1300	2200	59.09	49.15	.851
104.75	16.00	10.20	1[illegible]00	1950	61.50	53.50	.869
106.75	13.[illegible]5	9.25	1125	1700	66.18	55.43	.835
110.75	11.85	7.75	1075	1470	73.10	63.00	.860
112.75	9.90	6.75	910	1200	75.85	61.30	.810
115.75	8.15	5.20	700	950	73.60	61.10	.830
121.75	6.25	4.00	400	700	57.20	45.50	.875

For above test connection of compensating reactance was J to 6, and H to 12. Dial switch was placed on 1 and 7.

TABLE II.

Wood Alternator. Peaked Wave.

Impressed Voltage-220. Frequency-120 cycles.

E_{dc}	I_{dc}	I_{ac}	W_{dc}	W_{ac}	Efficiency	Apparent Efficiency	Power Factor
96.5	21.65	14.10	1900	2540	74.9	61.2	.820
98.5	19.85	12.70	1750	2340	74.8	6[illegible].6	.838
101.5	18.00	11.30	1600	2100	76.2	64.4	.845
102.5	16.00	10.10	1440	1840	78.3	64.9	.828
104.5	13.65	8.75	1325	1600	8[illegible].9	68.9	.830
107.5	11.85	7.50	1140	1360	83.9	69.0	.825
110.5	9.90	5.90	960	1100	87.2	74.0	.848
112.5	8.15	4.50	750	880	85.2	75.8	.890
117.5	6.25	3.30	500	600	83.4	63.1	.825

For above test connection of compensating reactance was J to [illegible], and H to 12. Dial switch was placed on 1-7.

TABLE III.

Rotary Converter. Sine Wave.

Impressed Voltage-220. Frequency-30 cycles.

E_{dc}	I_{dc}	I_{ac}	W_{dc}	W_{ac}	Efficiency	Apparent Efficiency	Power Factor
132	21.65	17.00	2550	3300	77.3	68.00	.883
133	19.85	15.00	2370	2940	80.6	71.90	.891
135	18.00	13.50	2190	2700	81.1	73.75	.910
136	16.00	11.65	1950	2340	83.5	76.00	.915
139	13.65	10.00	1675	2060	81.4	76.10	.937
141	11.85	8.65	1390	1700	81.9	73.00	.894
142	9.90	6.75	1050	1340	78.5	70.80	.904
144	8.15	5.00	750	1000	75.0	68.10	.910
146	6.25	3.60	470	700	67.10	59.40	.884

For above test connection of compensating reactance was J to 6, and H to 1[illegible]. Dial switch was placed on 1 and 7.

TABLE IV.

Holtzer-Cabot Set. Sine wave.

Impressed Voltage-220. Frequency-60 cycles.

E_{dc}	I_{dc}	I_{ac}	W_{dc}	W_{ac}	Efficiency	Apparent Efficiency	Power Factor
122	21.65	14.90	2240	3000	78.0	71.5	.915
124	19.85	13.10	2140	2700	79.3	74.4	.936
128	18.00	11.70	2010	2400	83.9	78.0	.933
129	16.00	10.20	1810	2160	84.0	80.6	.962
130	13.65	9.20	1590	1880	84.6	78.5	.930
132	11.85	7.75	1300	1540	84.5	76.3	.904
132	9.90	6.30	1050	1260	83.4	75.8	.910
135.5	8.15	5.00	820	1000	82.0	74.5	.910
139	6.25	3.60	500	660	75.9	63.0	.834

For above test connection of compensating reactance was J to 6, and H to 12. Dial switch was placed on 1 and 7.

TABLE V.

Westinghouse Alternator. Peaked Wave.

Impressed Voltage-110 Frequency-60 cycles.

E_{dc}	I_{dc}	I_{ac}	W_{dc}	W_{ac}	Efficiency	Apparent Efficiency	Power Factor
36.0	21.65	13.75	525	1200	43.75	34.74	.794
36.0	19.85	12.50	525	1120	46.85	38.20	.815
37.0	18.00	11.20	525	1000	52.50	42.60	.812
38.0	16.00	9.75	525	860	61.05	49.00	.801
40.0	13.65	8.50	500	740	67.50	53.50	.792
41.5	11.85	7.25	450	650	69.25	56.50	.815
43.5	9.90	6.00	350	530	66.00	53.00	.803
45.0	8.15	4.50	250	400	62.50	50.05	.809
46.4	6.25	3.60	175	300	58.35	44.20	.757

For above test connection of compensating reactance was J to 6, and H to 12. Dial switch was placed on 1 and 7.

TABLE VI.

Wood Alternator | Peaked Wave.

Impressed Voltage-110. | Frequency-120 cycles.

E_{dc}	I_{dc}	I_{ac}	W_{dc}	W_{ac}	Efficiency	Apparent Efficiency	Power Factor
31.5	21.65	13.50	700	1100	63.60	47.1	.740
33.5	19.85	12.20	650	1040	62.60	48.5	.775
34.5	18.00	11.15	580	940	61.70	47.3	.766
37.5	16.00	9.50	550	800	68.75	52.6	.765
39.5	13.65	8.25	460	700	65.70	50.7	.770
40.9	11.85	7.25	430	600	71.70	54.0	.752
42.0	9.90	5.85	340	480	70.80	52.8	.746
42.0	8.15	4.50	220	360	61.10	44.5	.727
45.0	6.25	3.60	150	300	50.00	37.9	.758

For above test connection of compensating reactance was J to 6, and H to 12. Dial switch was placed on 1 and 7.

TABLE VII.

Rotary Converter — Sine Wave

Impressed Voltage-110. — Frequency-30 cycles

E_{dc}	I_{dc}	I_{ac}	W_{dc}	W_{ac}	Efficiency	Apparent Efficiency	Power Factor
51.5	21.65	15.00	1020	1460	69.9	61.8	.885
53.0	19.85	13.25	960	1340	71.6	65.9	.920
54.5	18.00	11.80	890	1200	74.1	68.5	.924
56.1	16.00	10.30	800	1080	74.1	70.6	.954
57.5	13.65	9.20	700	940	74.5	69.2	.930
58.5	11.85	7.50	570	740	77.0	69.0	.896
59.5	9.90	6.50	450	640	70.4	63.0	.895
61.5	8.15	5.20	350	500	70.0	61.1	.875
63.0	6.25	3.60	230	360	64.0	58.0	.910

For above test connection of compensating reactance was J to 6, and H to 12. Dial switch was placed on 1 and 7.

TABLE VIII.

Holtzer-Cabot Set. Sine Wave.

Impressed Voltage-110. Frequency-60 cycles.

E_{dc}	I_{dc}	I_{ac}	W_{dc}	W_{ac}	Efficiency	Apparent Efficiency	Power Factor
93.0	21.65	14.00	870	1340	65.00	56.5	.870
95.0	19.85	12.50	810	1220	66.40	59.0	.887
98.0	18.00	11.30	790	1140	69.30	63.5	.918
102.0	16.00	9.80	710	1000	71.00	65.9	.928
104.2	13.65	8.75	600	860	69.75	62.4	.894
106.0	11.85	7.25	500	700	71.50	62.7	.878
110.0	9.90	6.00	440	600	73.50	66.0	.910
113.0	8.15	4.50	340	480	71.00	68.7	.900
116.0	6.25	3.60	230	360	64.00	58.0	.910

For above test connection of compensating reactance was J to 6, and H to 12. Dial switch was placed on 1 and 7.

TABLE II.

Westinghouse Alternator. Frequency-60 cycles.

Impressed Voltage-220. Motor Load.

E_{dc}	I_{dc}	I_{ac}	W_{dc}	W_{ac}	Efficiency	Apparent Efficiency	Power Factor
111.0	10.40	6.80	1000	1280	78.0	66.9	.855
110.5	10.75	7.25	1050	1340	78.3	65.9	.840
108.0	11.70	7.80	1100	1440	76.4	64.1	.840
107.0	13.75	9.25	1270	1700	74.6	62.4	.835
106.5	16.00	11.00	1500	2000	75.0	62.0	.826
105.5	17.00	12.00	1690	2240	75.4	64.0	,848
105.5	20.00	13.50	1880	2500	75.1	63.3	.841
104.5	21.75	14.80	2050	2760	74.3	63.0	.848
103.0	23.75	16.30	2230	3000	74.4	62.2	.837

Starting current, no load is 45 amperes.

Running current, no load is 10 amperes.

For the above test the connection of compensating reactance was J to 6, and H to 12. Dial switch was placed on 1 and 7.

TABLE X.

Westinghouse Alternator. Frequency-60 cycles.

Impressed Voltage-220. Arc Lamp Load.

110 Volt Lamps.

E_{dc}	I_{dc}	I_{ac}	W_{dc}	W_{ac}	Eff.	App. Eff.	P.F.	No. of Lamps
101.0	22.60	16.10	2200	2920	75.4	62.1	.825	1
105.5	18.00	12.50	1750	2300	76.0	65.7	.837	2
107.0	12.75	8.75	1250	1600	78.0	65.0	.830	3
114.5	7.25	4.35	650	800	81.0	67.9	.835	4

For the above test connection of compensating reactance was J to 6, and H to 12. Dial switch was placed on 1 and 7.

TABLE XI.

Voltage Characteristic. Frequency-60 cycles.

Westinghouse Alternator. Peaked Wave.
Full load.

Line	E_{dc}	E_{ac}	W_{dc}	W_{ac}	Eff.	Compensating Reactance	Dial Switch
220	98	325	2000	2640	75.7	J-6, H-12	1-7
220	91	304	1825	2500	73.0		2-8
220	84	284	1750	2350	74.5		3-9
220	76	261	1650	2160	76.4		4-10
220	70	240	1500	2000	75.0		5-11
220	62	217	1275	1840	69.4		6-12
220	57	223	1225	1700	72.0	J-1, H-7	1-7
220	52	207	1100	1600	68.9		2-8
220	47	193	1000	1500	66.6		3-9
220	42	175	960	1400	68.5		4-10
220	42	165	900	1280	70.4		5-11
220	36	150	750	1200	62.5		6-12
110	33	151	730	1160	63.0	J-6, H-12	1-7

TABLE XII.

Voltage Characteristic. Frequency -60 cycles.

Westinghouse Alternator. Peaked Wave.

Three-quarter Load.

Line	Edc	Eac	Wdc	Wac	Eff.	Compensating Reactance	Dial Switch
220	102	325	1450	2060	70.5	J-6, H-12	1-7
220	95	303	1440	1900	75.9		2-8
220	88	283	1300	1820	71.5		3-9
220	80	262	1160	1680	69.0		4-10
220	73	238	1100	1540	71.5		5-11
220	64	216	1100	1400	78.5		6-12
220	65.5	226	1030	1300	79.2	J-1, H-7	1-7
220	59.5	210	925	1240	74.5		2-8
220	55.0	195	875	1160	75.5		3-9
220	49.5	181	740	1080	68.5		4-10
220	45.	166	600	1000	60.0		5-11
220	39	150	445	900	49.4		6-12
110	35.5	160	450	900	50.0	J-6, H-12	1-7
110	34.	151.5	400	800	50.0		2-8
110	30.5	141	400	760	52.6		3-9
110	27.0	131	350	700	50.0		4-10
110	25.5	119	300	640	46.9		5-11
110	20.0	109	280	600	46.6		6-12

TABLE XIII.

Voltage Characteristic. Frequency-60 cycles.

Westinghouse Alternator. Peaked Wave.

One Half Load.

Line	E_{dc}	E_{ac}	W_{dc}	W_{ac}	Eff.	Compensating Reactance	Dial Switch
220	108	325	1200	1420	84.5	J-6, H-12	1-7
220	100	302	1100	1320	83.3		2-8
220	92.5	280	950	1280	74.4		3-9
220	83.0	256	900	1200	75.0		4-10
220	76.0	235	850	1100	77.3.		5-11
220	73.0	217	740	1004	73.7		6-12
220	68.5	225	650	900	72.2	J-1, H-7	1-7
220	62.6	209	630	860	73.2		2-8
220	57.	194	550	800	68.7		3-9
220	51.5	179	500	700	71.4		4-10
220	46.	163	450	640	70.3		5-11
220	40.5	148	430	600	71.6		6-12
220	40.5	162	450	600	75.0	J-6, H-12	1-7
220	37.	145	380	560	68.0		2-8
220	33.	143	350	500	70.0		3-9
220	30.	132	330	480	68.7		4-10
220	26.	121	270	440	61.4		5-11
220	22.	109.5	240	400	60.0		6-12
220	20.5	111.	200	360	55.5	J-1, H-7	1-7
220	16.	103	200	320	62.5		2-8
220	15.	96	190	300	63.4		3-10
220	10.	88	150	280	53.6		4-11
220	2.	81.5	150	280	53.6		5-12

TABLE XIV.

Voltage Characteristic. Frequency -60 cycles.

Westinghouse Alternator. Peaked Wave.

One-quarter Load

Line	E_{dc}	E_{ac}	W_{dc}	W_{ac}	Eff.	Compensating Reactance	Dial Switch
220	118	315	660	800	82.5	J-6, H-12	1-7
220	109	295	550	740	74.4		2-8
220	101	273	550	680	81.0		3-9
220	92	252	480	640	75.0		4-10
220	83	230	450	600	75.0		5-11
220	74	208	360	540	66.7		6-12
220	71	218	350	480	73.0	J-1, H-7	1-7
220	66	205	330	420	78.5		2-8
220	60.5	191	290	400	72.5		3-9
220	55.	176	260	360	72.2		4-10
220	49	160	250	320	78.1		5-11
220	48.5	146	210	300	70.0		6-12
110	44.5	162	170	300	56.6	J-6, H-12	1-7
110	41.0	152	150	260	57.7		2-8
110	37.0	141	140	240	58.3		3-9
110	32.5	131	130	240	54.1		4-10
110	28.	119	80	200	40.0		5-11
110	23.	126	120	200	60.0		6-12
110	21.5	110	90	200	45.0	J-1, H-7	1-7
110	18	103	60	160	37.5		2-8
110	16	96	50	140	35.7		3-9
110	12	87	50	120	41.6		4-10
110	5	79	50	100	50.0		5-11
110	-	73.5	50	100	50.0		6-12

TABLE XV.

Voltage Characteristic. Frequency-120 cycles.

Wood Generator. Peaked Wave.

Full Load.

Line	E_{dc}	E_{ac}	W_{dc}	W_{ac}	Compensating Reactance	Dial Switch
220	98.5	325	1750	2300	J-6, H-12	1-7
220	91.5	303	1600	2160		2-8
220	84.5	284	1540	2060		3-9
220	76.5	261.5	1370	1900		4-10
220	69.5	238.0	1250	1760		5-11
220	61.5	217	1120	1600		6-12
220	65.0	223	1170	1540	J-1, H-7	1-7
220	60.0	210	1070	1460		2-8
220	54.5	195	990	1360		3-9
220	47.5	179	900	1260		4-10
220	42.0	164.5	770	1140		5-11
220	37.5	149	670	1080		6-12
110	33.5	161	540	1006	J-6, H-12	1-7
110	30.5	148	490	1000		2-8
110	27.5	139	450	900		3-9
110	24.5	130	430	840		4-10
110	21.5	119	370	800		5-11
110	18.5	108.5	350	700		6-12

TABLE XVI.

Voltage Characteristic.
Wood Generator.

Frequency-120 cycles
Peaked Wave.

One half Load.

Line	Edc	E_{ac}	W_{dc}	W_{ac}	Compensating Reactance	Dial Switch
220	107	323	1060	1120	J-6, H-12	1-7
220	100	300	960	1080		2-8
220	92	280	890	1000		3-9
220	83	257.5	850	940		4-10
220	75	238	730	880		5-11
220	67	212	540	680		6-12
220	70	222	670	700	J-1. H-7	1-7
220	65	202	640	640		2-8
220	58	191	540	600		3-9
220	52	178	500	560		4-10
220	46	163	450	500		5-11
220	40	146	360	460		6-12
110	40	163	300	480	J-6, H-12	1-7
110	37	153	260	440		2-8
110	34	142	240	400		3-9
110	30	132	200	360		4-10
110	25	119	150	320		5-11
110	22	108	140	300		6-12
110	20	111	200	300	J-1, H-7	1-7
110	18	103	160	260		2-8
110	15	96	140	240		3-9
110	10	88.5	130	200		4-10
110	5	80.5	100	200		5-11
110	-	72.5	90	200		6-12

TABLE XVII.

Voltage Characteristic.
Rotary Converter.
Full Load.

Frequency-3[illegible] cycles.
Sine Wave.

Line	Edc	Eac	Wdc	Wac	Compensating Reactance	Dial Switch
220	117	284	2150	2660	J-6. H-12	1-7
220	109	264	1975	2500		2-8
220	102	246	1800	2300		3-9
220	92	224	1650	2160		4-10
220	83	206	1540	2000		5-11
220	75	186	1350	1800		6-12
220	81	213	1500	1900	J-1. H-7	1-7
220	76	199	1400	1800		2-8
220	70	182	1360	1690		3-9
220	62	168	1200	1520		4-10
220	55	152	1070	1420		5-11
220	48	119	970	1300		6-12
110	52	159	910	1360	J-6, H-12	1-7
110	48.5	150	860	1280		2-8
110	45.0	138	770	1200		3-9
110	41.0	130	750	1120		4-10
110	36.0	119	670	1040		5-11
110	32.0	106.5	630	920		6-12
110	25.0	100.5	490	800	J-1. H-7	1-7
110	22.0	92.	440	700		2-8

TABLE XVIII.

Voltage Characteristic.
Rotary Converter.
One Half Load.

Frequency-30 cycles.
Sine Wave.

Line	E_{dc}	E_{ac}	W_{dc}	W_{ac}	Compensating Reactance	Dial Switch
220	141	304	1140	1400	J-6. H-12	1-7
220	130	286	1040	1300		2-8
220	120	264	920	1240		3-9
220	111	246	850	1160		4-10
220	101	225	790	1080		5-11
220	91	203	730	1000		6-12
220	87	208	760	900	J-1, H-7	1-7
220	80	195.5	670	840		2-8
220	74	181.2	650	800		3-9
220	66	165.0	550	700		4-10
220	58	148.5	520	660		5-11
220	52	134.0	470	600		6-12
110	58	156.0	450	600	J-6, H-12	1-7
110	54	147.0	450	560		2-8
110	49.5	136.0	440	520		3-9
110	45	127.0	370	500		4-10
110	40	117.5	350	420		5-11
110	35.5	105.0	300	400		6-12
110	33	107.0	250	400	J-1.H-7	1-7
110	29	99.6	250	340		2-8
110	25	92.5	230	300		3-9
110	22	85.0	160	280		4-10
110	18	76.0	150	260		5-11
110	15	68.8	130	240		6-12

TABLE XIV.

Voltage Characteristic. Frequency -60 cycles.
Holtzer Cabot Set. Sine Wave.
FULL LOAD.

Line	E_{dc}	E_{ac}	W_{dc}	W_{ac}	Compensating Reactance	Dial Switch
220	124	318	2190	2760	J-6, H-12	1-7
220	115	296	2000	2580		2-8
220	106	277	2810	2900		3-9
220	99	254	1650	2240		4-10
220	90	233	1550	2100		5-11
220	80	212	1350	1900		6-12
220	76	217	1130	1800	J-1. H-12	1-7
220	70	201	1140	1700		2-8
220	64	184	1130	1540		3-9
220	56	170	1150	1460		4-10
220	50	155	940	1300		5-11
220	44	139	850	1240		6-12
110	47	163	770	1240	J-6. H-12	1-7
110	44	153	770	1160		2-8
110	40.5	142	740	1100		3-9
110	36	131	670	1040		4-10
110	33	120	630	960		5-11
110	28	109	550	860		6-12
110	26	111	430	840	J-1, H-7	1-7
110	23	103	370	800		2-8
110	20	95.5	370	740		3-9

TABLE IX.

Voltage Characteristic. Frequency-60 cycles.
Holtzer-Cabot Set. Sine Wave.
One Half Load.

Line	I dc	E ac	W dc	W ac	Compensating Reactance	Dial Switch
220	135	310	1050	1300	J-6. H-12	1-7
220	124	304	1060	1200		2-8
220	114	270	960	1160		3-9
220	104	245	850	1080		4-10
220	95	227	780	1000		5-11
220	87	205	690	900		6-12
220	80	210	[illegible]	[illegible]	J-1, H-7	1-7
220	74	197	590	800		2-8
220	68	181	550	760		3-9
220	60	166	500	700		4-10
220	54	152	450	[illegible]		5-11
220	46	137	380	600		6-12
110	54.5	160	410	600	J-6, H-12	1-7
110	49.5	150	370	560		2-8
110	45.	138	350	500		3-9
110	40.5	128	330	480		4-10
110	36.	117	270	400		5-11
110	31.	106.5	250	400		6-12
110	30.	109	240	400	J-1, H-7	1-7
110	25	101	230	300		2-8
110	23	94	170	300		3-9
110	20	89.5	150	260		4-10
110	15	77.5	140	240		5-11
110	10	70.5	130	200		6-12

TABLE XXI.

Variation of Effective E. M. F. with Constant Average E. M. F. s at Various Loads.

Westinghouse Alternator.
Frequency-60 cycles.

Line Voltage	E_{dc}	E'_{dc}	I_{dc}
115.5	110	110.2	21.65
115.0	110	115.8	19.85
113.5	110	115.8	18.00
112.5	110	116.5	16.00
111.4	110	117.0	13.65
110.5	110	117.4	11.85
109.6	110	118.5	9.90
108.5	110	119.5	8.15
108.5	110	122.5	6.25
108.4	100	98.7	21.65
108.0	100	99.7	19.85
105.5	100	100.3	18.00
104.3	100	100.5	16.00
103.1	100	101.5	13.65
102.2	100	102.5	11.85
101.5	100	103.5	9.90
101.0	100	106.5	8.15
100.0	100	110.5	6.25
100.0	90	88.7	21.65
98.5	90	88.7	19.85
97.0	90	88.7	18.00
94.5	90	90.7	16.00
93.8	90	90.7	13.65
92.8	90	92.7	11.85
91.8	90	94.7	9.90
91.0	90	97.7	8.15
96.7	90	89.7	6.25
91.0	80	76.7	21.65
90.0	80	76.7	19.85
88.5	80	76.4	18.00
87.1	80	77.2	16.00
86.0	80	78.2	13.65
85.2	80	78.7	11.85
83.7	80	79.7	9.90
83.2	80	81.7	8.15
82.5	80	83.7	6.25

For above test connection of compensating reactance was J to 6, and H to 12. Dial switch was placed on 1 and 7.

TABLE XXII.

Mercury Arc Rectifier Measurements.

Shown by Plate XXIV.

Normal conditions, full load with impressed E.M.F.220, 60 cycles

Refer to Plate XXIV.

V_1-57.5	V_2-188	V_3-222	V_4-220	V_5-100
I_1-13.5	I_2-13.5	I_3-20	I_4-20	

Refer to Plate IV.

J-6, H-12 Dial Switch 6-12.

The current in line H --8.4 amperes

" " "anode E -12.6 "

" " " load D -20.0 "

Refer to Plate IV.

Drop over one compensating coil 1-D--188 volts.

" " 1/2 one " " 6-D--120 "

" " one " " 1-anode--222 volts

" " 1/2 one " " 6- " --128 "

With condition of full load, short circuit.

E_{ac}	I_{ac}	E_{dc}	I_{dc}
41.0	13.5	0	20

The minimum load is always 45 amperes.

" " line E.M.F. is always 27.5 volts.

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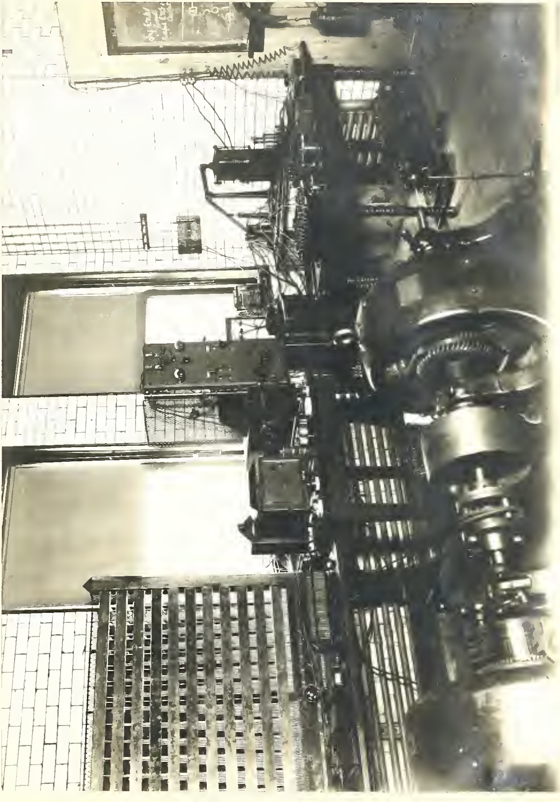
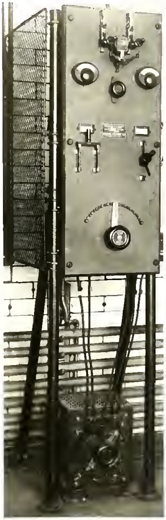
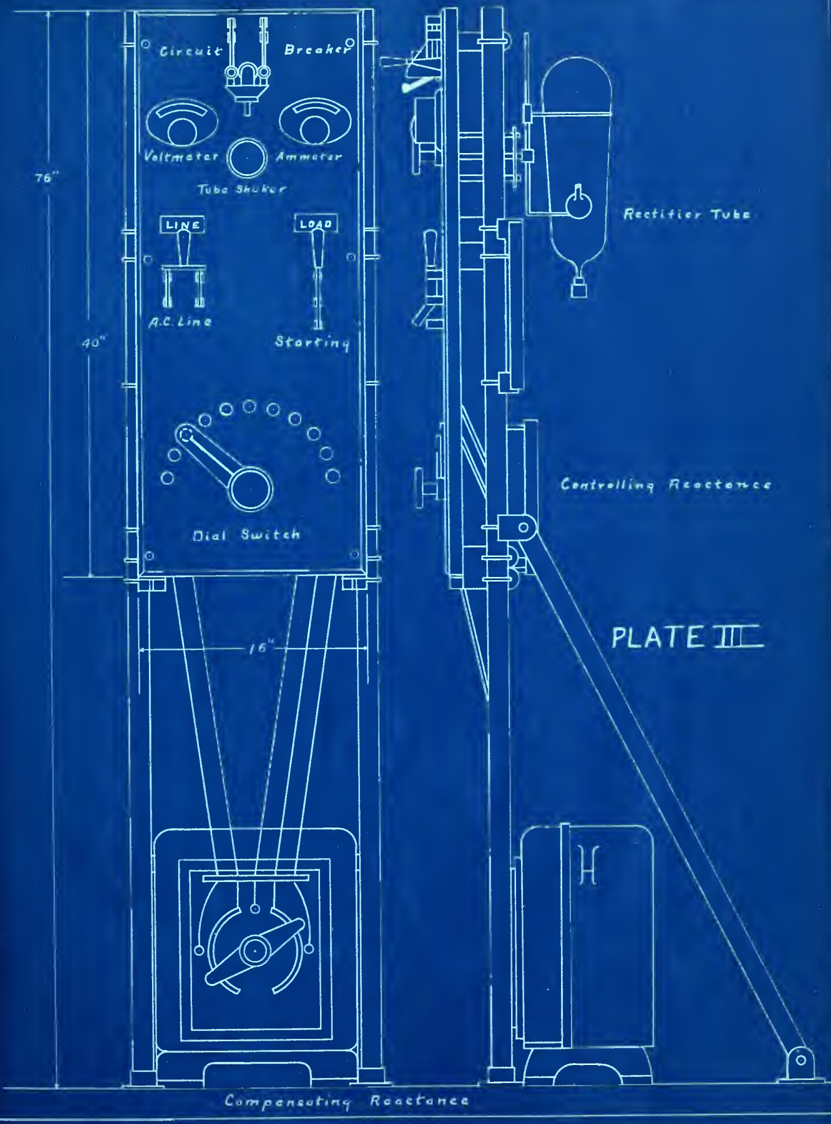




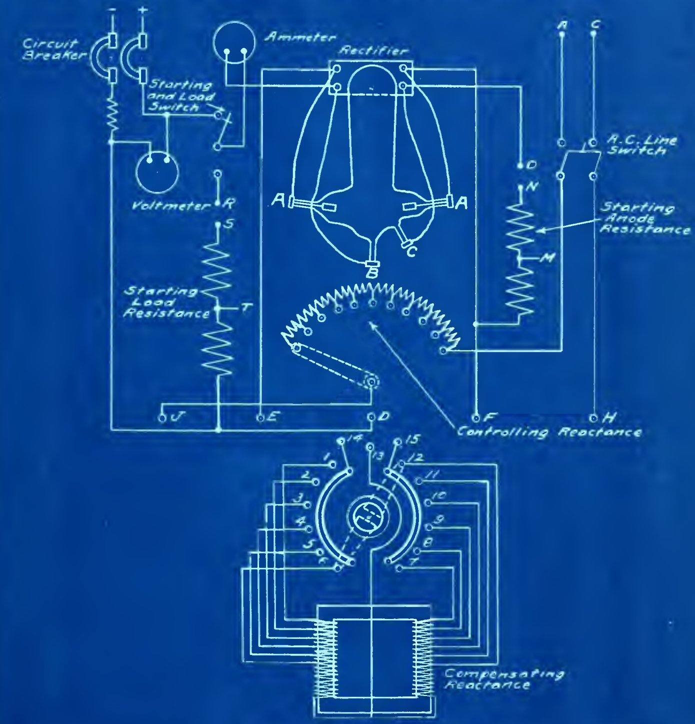


Circuit Breaker
Voltmeter
Ammeter
Tube Shaker
LINE
LOAD
A.C. Line
Starting
Dial Switch
76"
40"
16"
Rectifier Tube
Controlling Reactance
Compensating Reactance

PLATE III

PLATE IV.

CONNECTIONS OF MERCURY ARC RECTIFIER PANEL.



Connect E to 14, D to 13, F to 15.

110 V. A.C. Line Voltage { For 15 to 30 Volts D.C. Connect J to 1, H to 7, R to T, and O to M.
" 30 " 45 " " " " J " 6, H " 12, R " S, " O " N.

110-220 V. A.C. Line Voltage { Use 110 V. A.C. { For 30 to 45 Volts D.C. Connect J to 6, H to 12, R to T, and O to M.
Use 220 V. A.C. " 40 " 75 " " " " J " 1, H " 7, R " S, " O " N.

220 V. A.C. Line Voltage { For 45 to 75 Volts D.C. Connect J " 1, H to 7, R to T, and O to M.
" 75 " 115 " " " " J " 6, H " 12, R " S, " O " N.

330 V. A.C. " " { For 90 " 120 Volts D.C. Connect J " 1, H to 7, R to T, and O to M.
" 120 " 175 " " " " J " 6, H " 12, R " S, " O " N.

M-3-25-07.

PLATE V.

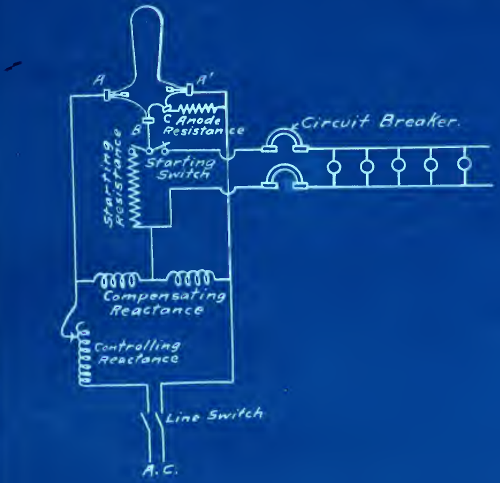


FIG. 1.

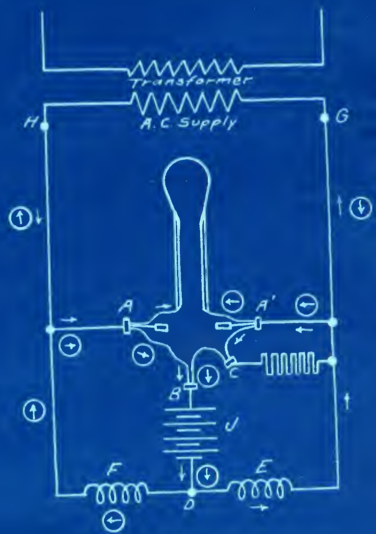


FIG. 2.

PLATE VI

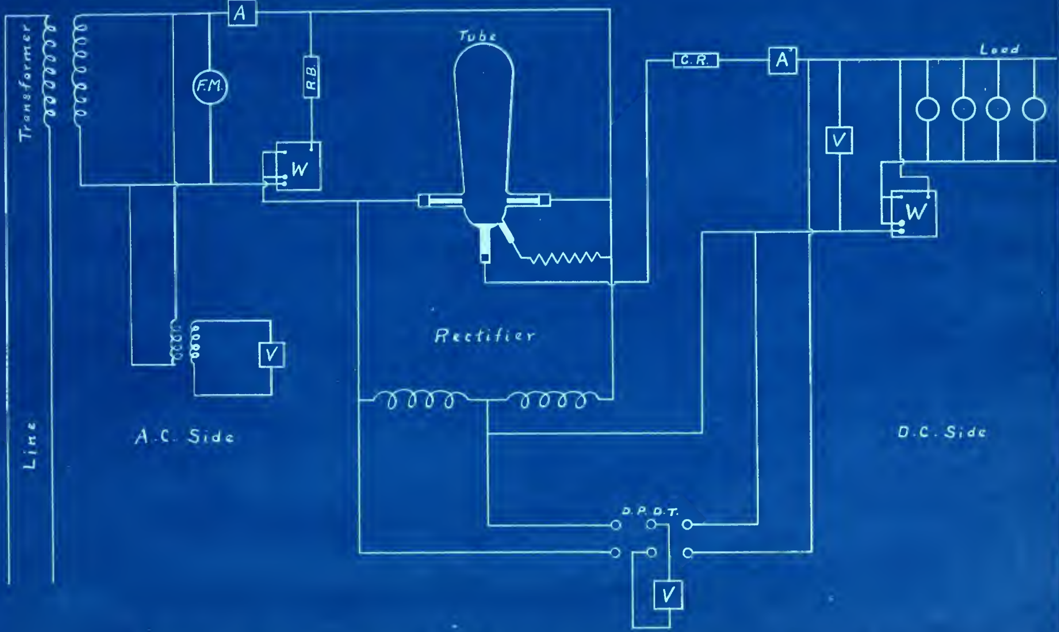
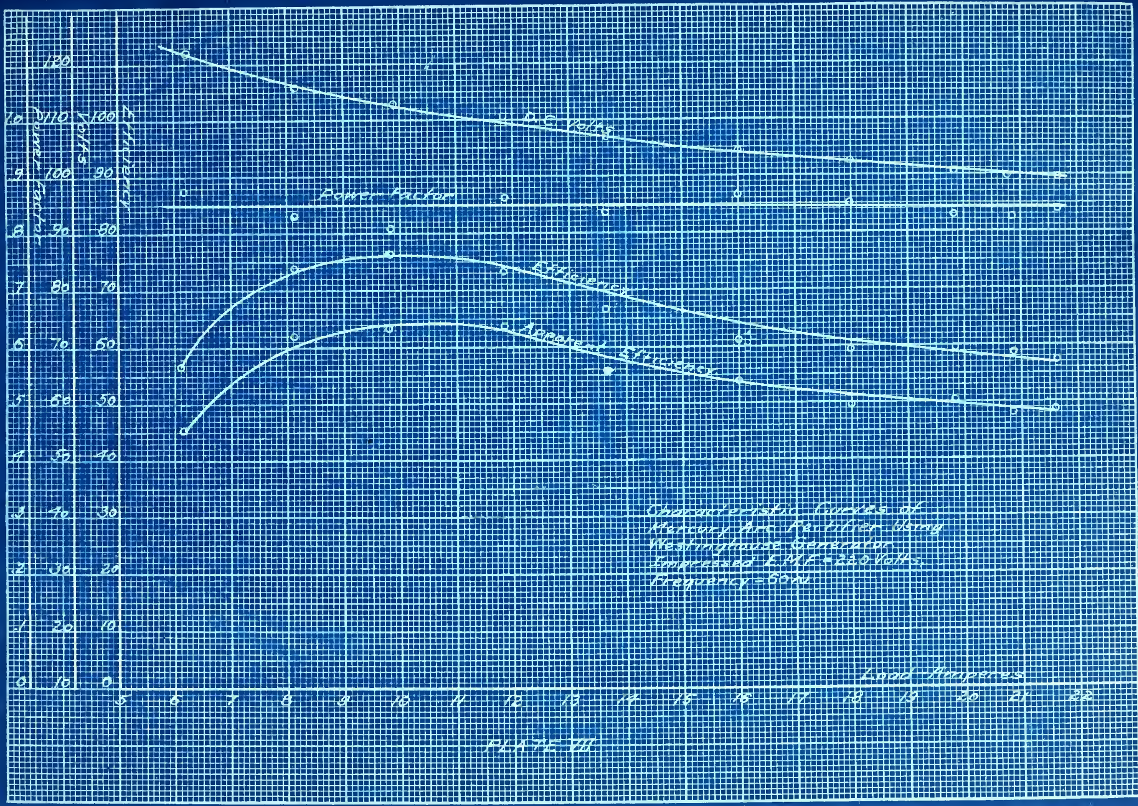


Diagram of Rectifier and Wiring Scheme for Experimental Investigation



D.C. Volts
Power Factor
Efficiency
Apparent Efficiency
Characteristic Curves of
Mercury Arc Rectifier Using
Westinghouse Generator
Impressed E.M.F. = 220 Volts.
Frequency = 60~
Load Amperes
Power Factor
Volts
Efficiency

PLATE III

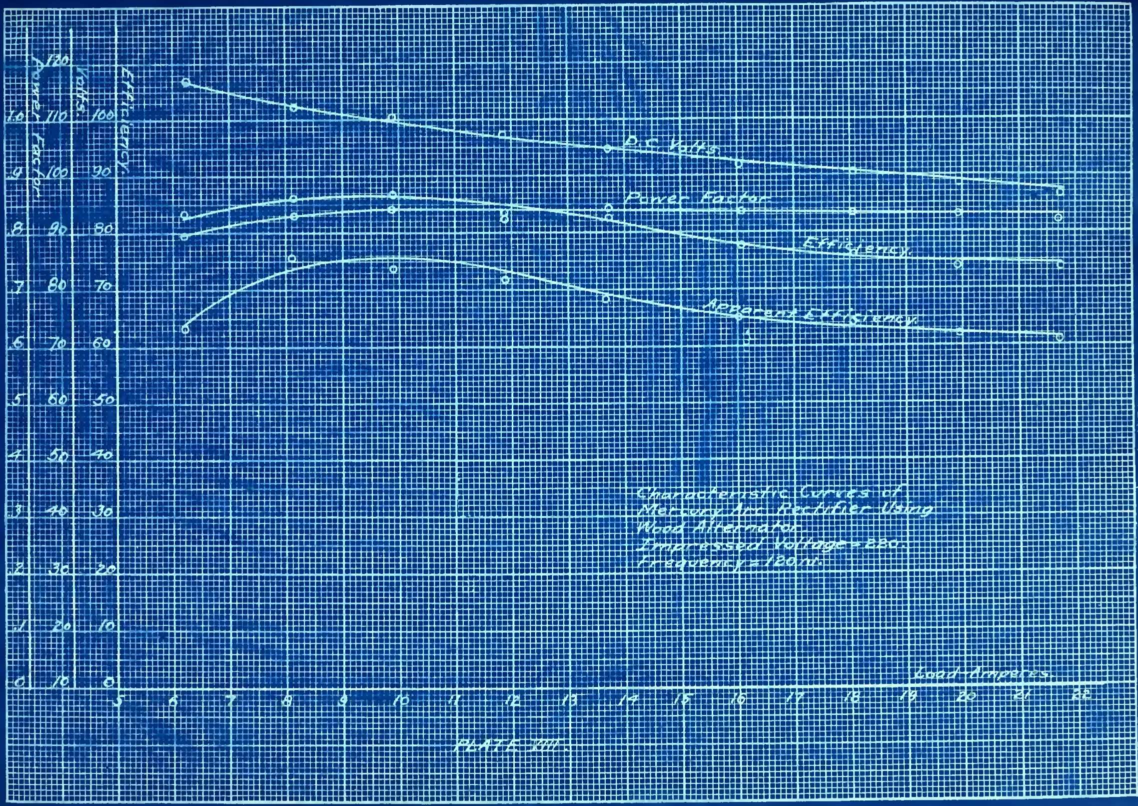
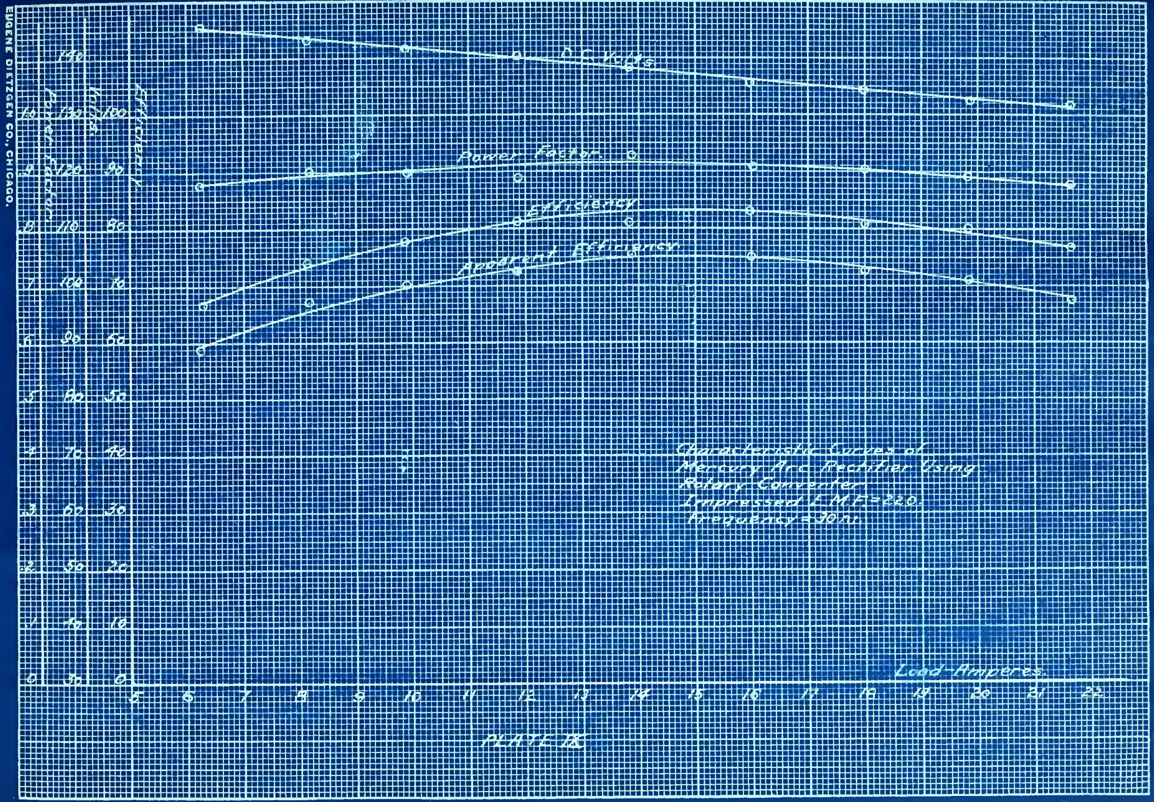
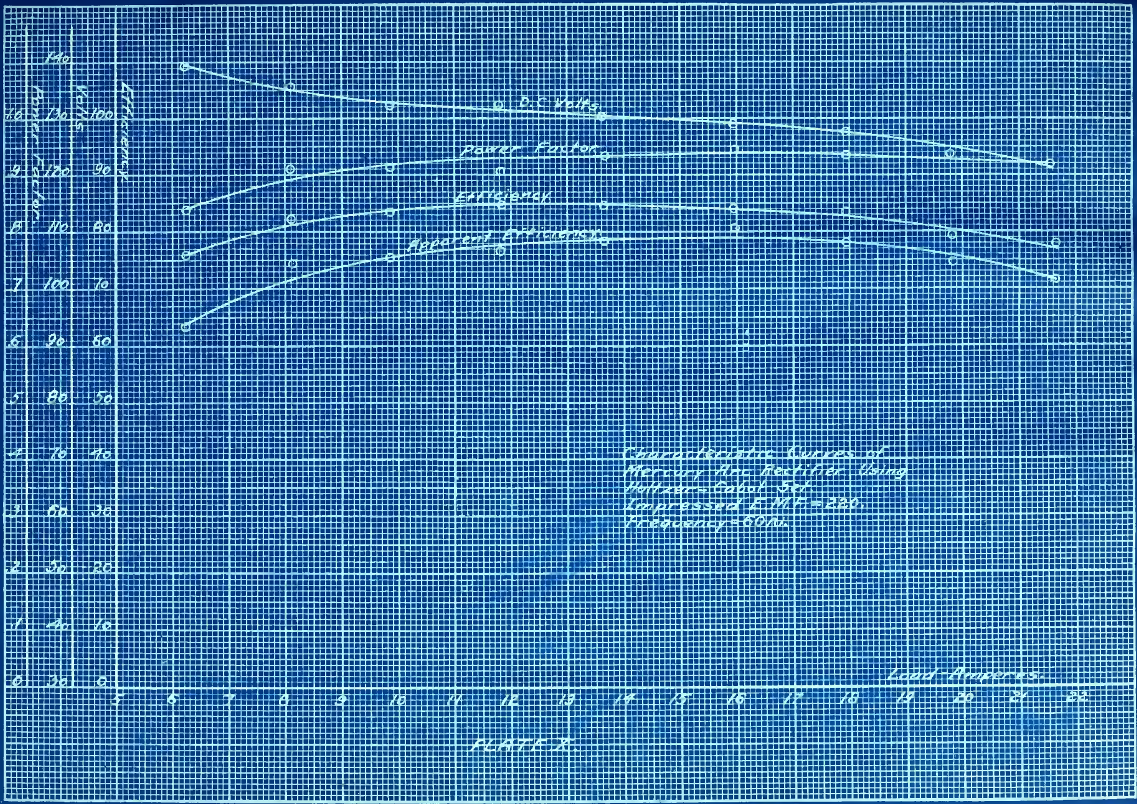

Power Factor
Volts.
Efficiency.
D.C. Volts.
Power Factor
Efficiency.
Apparent Efficiency.
Characteristic Curves of
Mercury Arc Rectifier Using
Wood Alternator.
Impressed Voltage = 220.
Frequency = 120 ~.
Load Amperes.
EUGENE DIETZGEN CO., CHICAGO.

PLATE XIII.



D.C. Volts
Power Factor
Efficiency
Apparent Efficiency
Characteristic Curves of
Mercury Arc Rectifier Using
Rotary Converter
Impressed E.M.F.=220.
Frequency=30 ~
Load-Amperes
Efficiency
Volts
Power Factor
PLATE
EUGENE DIETZGEN CO., CHICAGO.



Characteristic Curves of
Mercury Arc Rectifier Using
Holtzer-Cabot Set.
Impressed E.M.F.=220.
Frequency=60~.
D.C. Volts
Power Factor
Efficiency
Apparent Efficiency
Efficiency
Volts
Power Factor
Load Amperes.
EUGENE DIETZGEN CO., CHICAGO.

PLATE X.

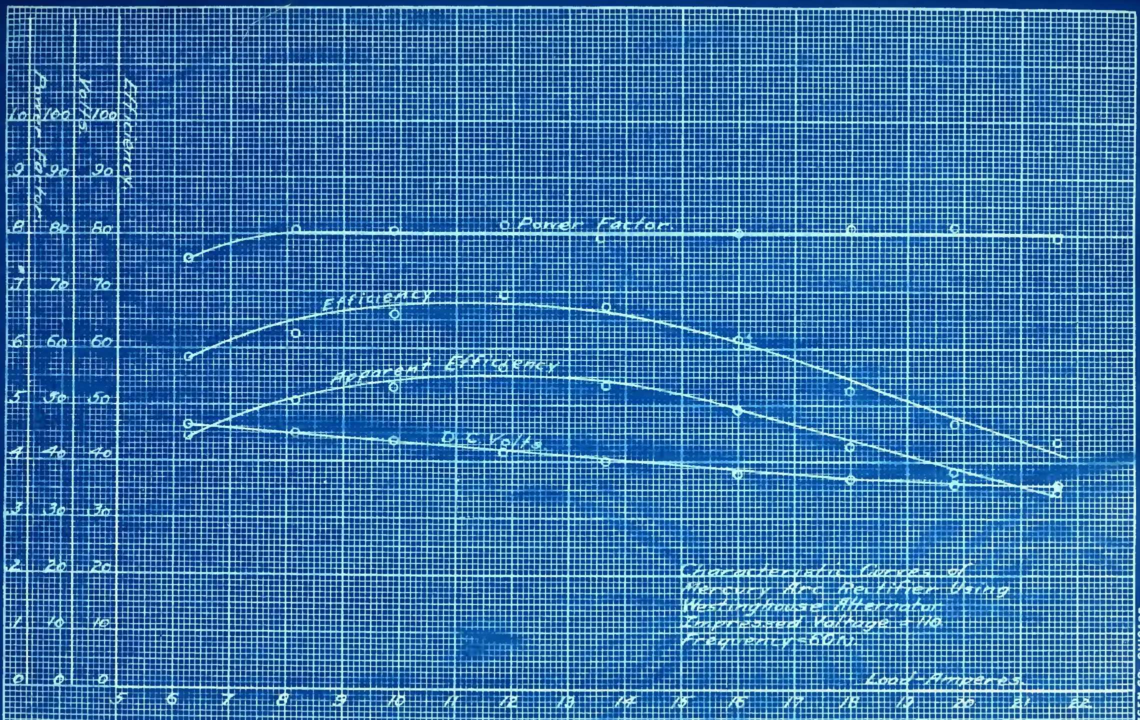
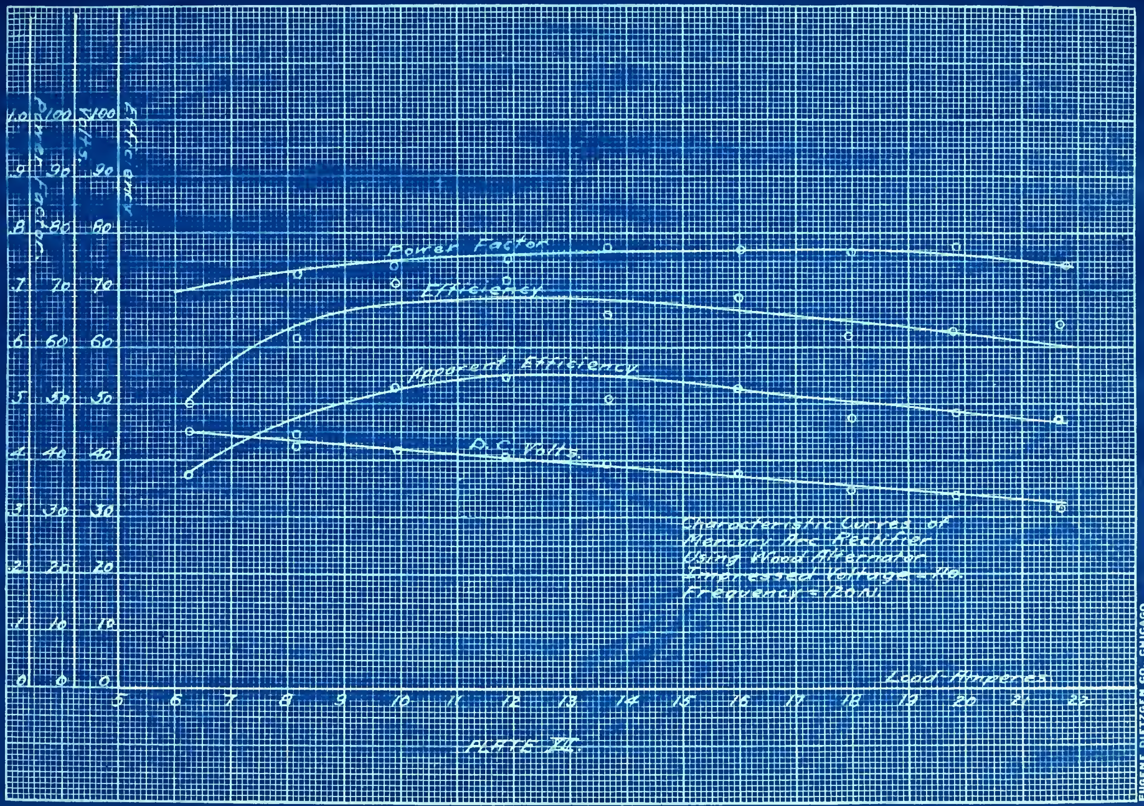

Power Factor
Volts
Efficiency
Power Factor
Efficiency
Apparent Efficiency
D.C. Volts
Characteristic Curves of
Mercury Arc Rectifier Using
Westinghouse Alternator
Impressed Voltage = 110
Frequency = 60 ~.
Load-Amperes.

PLATE XI.



Power Factor
Volts.
Efficiency
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
100
90
80
70
60
50
40
30
20
10
0
Power Factor
Efficiency
Apparent Efficiency
D.C. Volts.
Characteristic Curves of
Mercury Arc Rectifier
Using Wood Alternator
Impressed Voltage = 110
Frequency = 120 ~
Load Amperes
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
PLATE XI.
EUGENE DIETZGEN CO., CHICAGO.

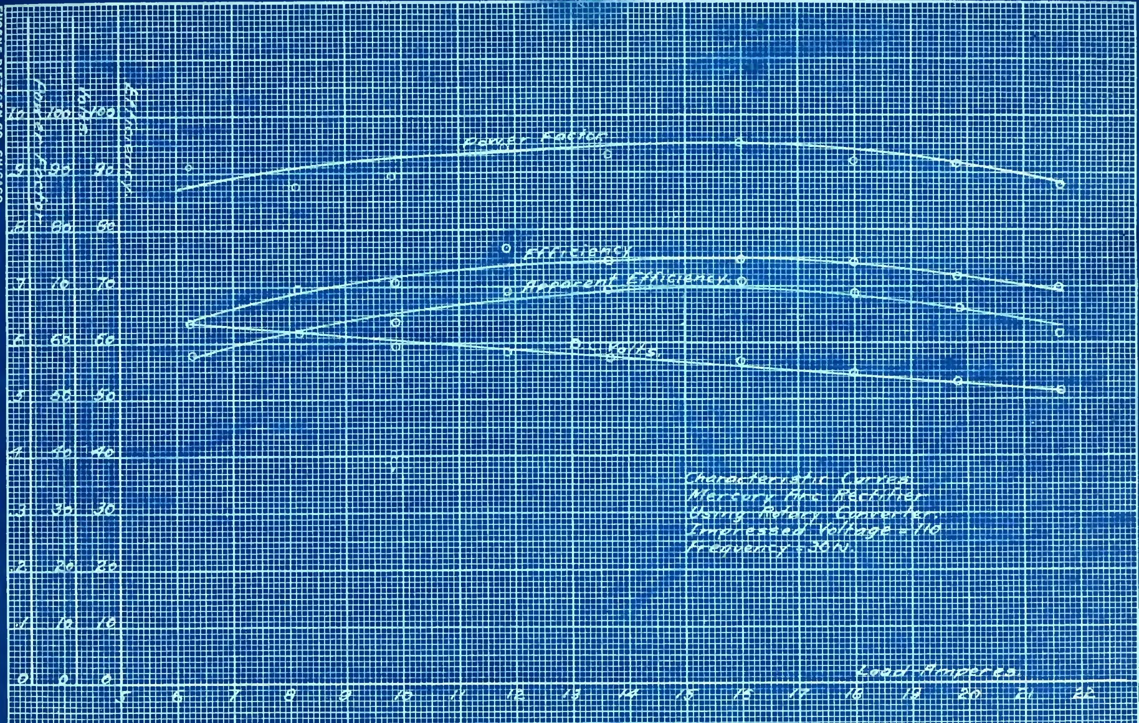

Power Factor
Volts
Efficiency
10 100 100
.9 90 90
.8 80 80
.7 70 70
.6 60 60
.5 50 50
.4 40 40
.3 30 30
.2 20 20
.1 10 10
0 0 0
Power Factor
Efficiency
Apparent Efficiency
Volts
Characteristic Curves
Mercury Arc Rectifier
Using Rotary Converter.
Impressed Voltage = 110
Frequency = 30 ~
Load Amperes.
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

PLATE XIII.

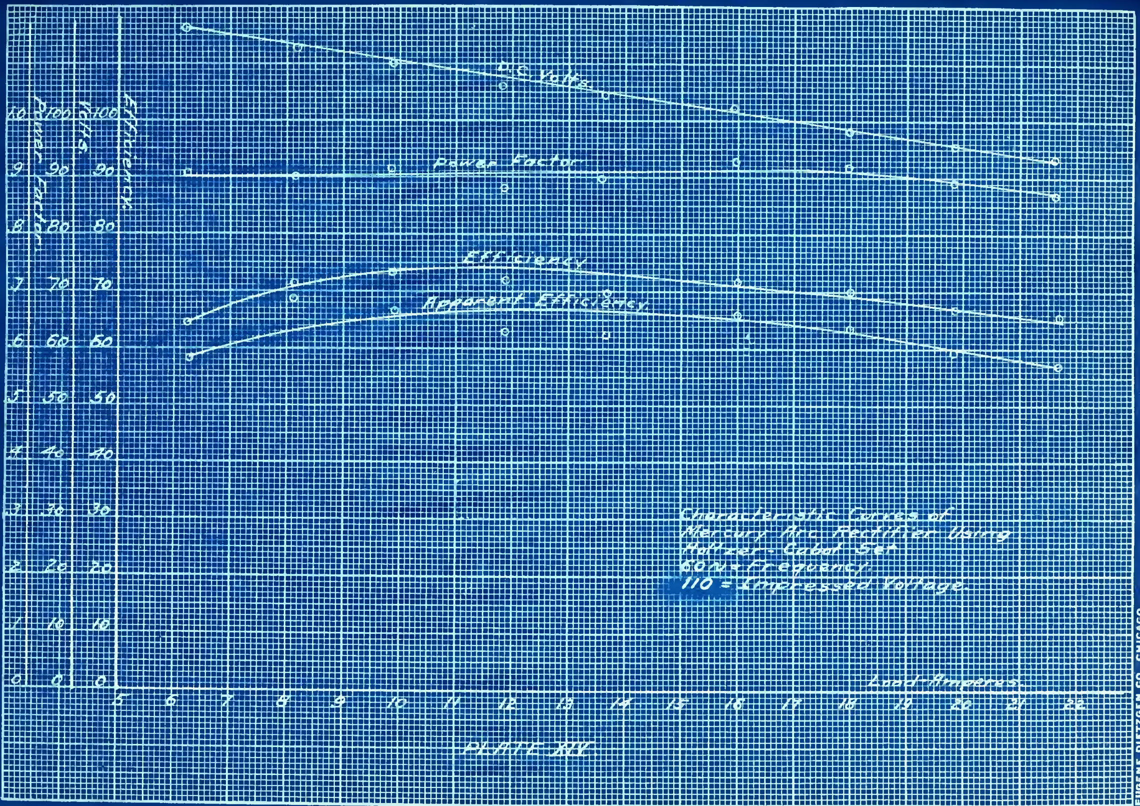

D.C. Volts
Power Factor
Efficiency
Apparent Efficiency
Characteristic Curves of
Mercury Arc Rectifier Using
Holtzer-Cabot Set
60 ~ = Frequency
110 = Impressed Voltage
Load Amperes
Efficiency
Volts
Power Factor
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
0 10 20 30 40 50 60 70 80 90 100
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

PLATE XIV

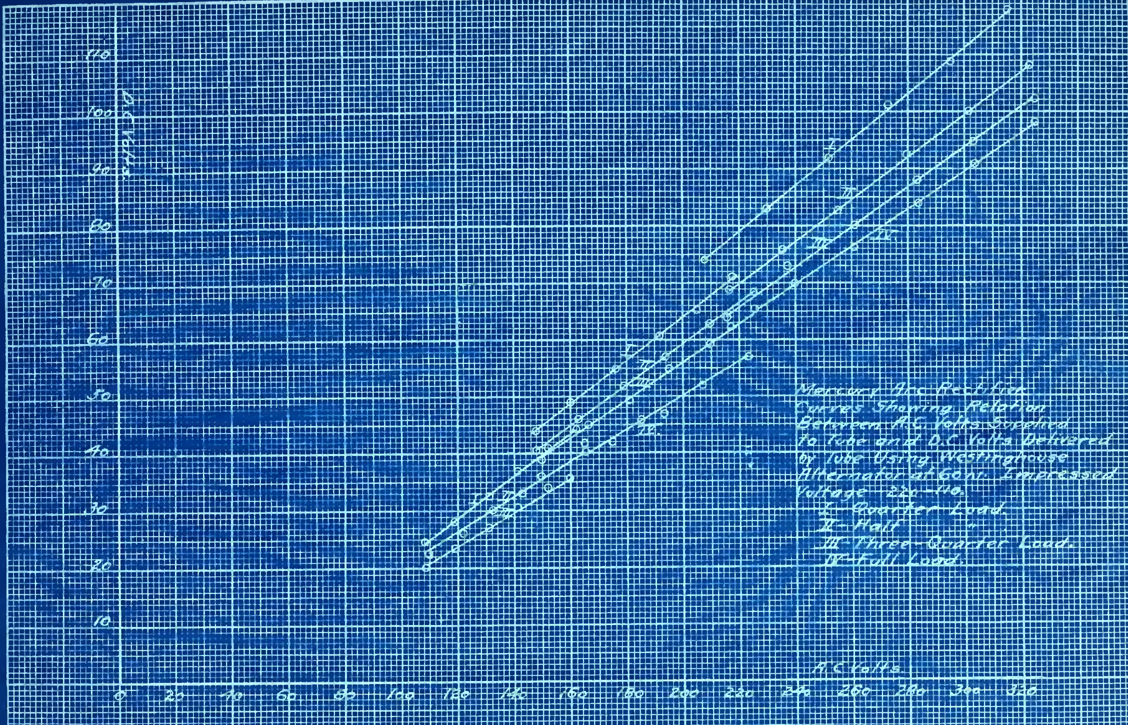

Mercury Arc Rectifier
Curves Showing Relation
Between A.C. Volts Supplied
to Tube and D.C. Volts Delivered
by Tube Using Westinghouse
Alternator at 60 ~ Impressed
Voltage 220-110.
I - Quarter Load.
II - Half "
III - Three-Quarter Load.
IV - Full Load.
D.C. Volts
A.C. Volts
0
10
20
30
40
50
60
70
80
90
100
110
120
140
160
180
200
220
240
260
280
300
320

PLATE XV.

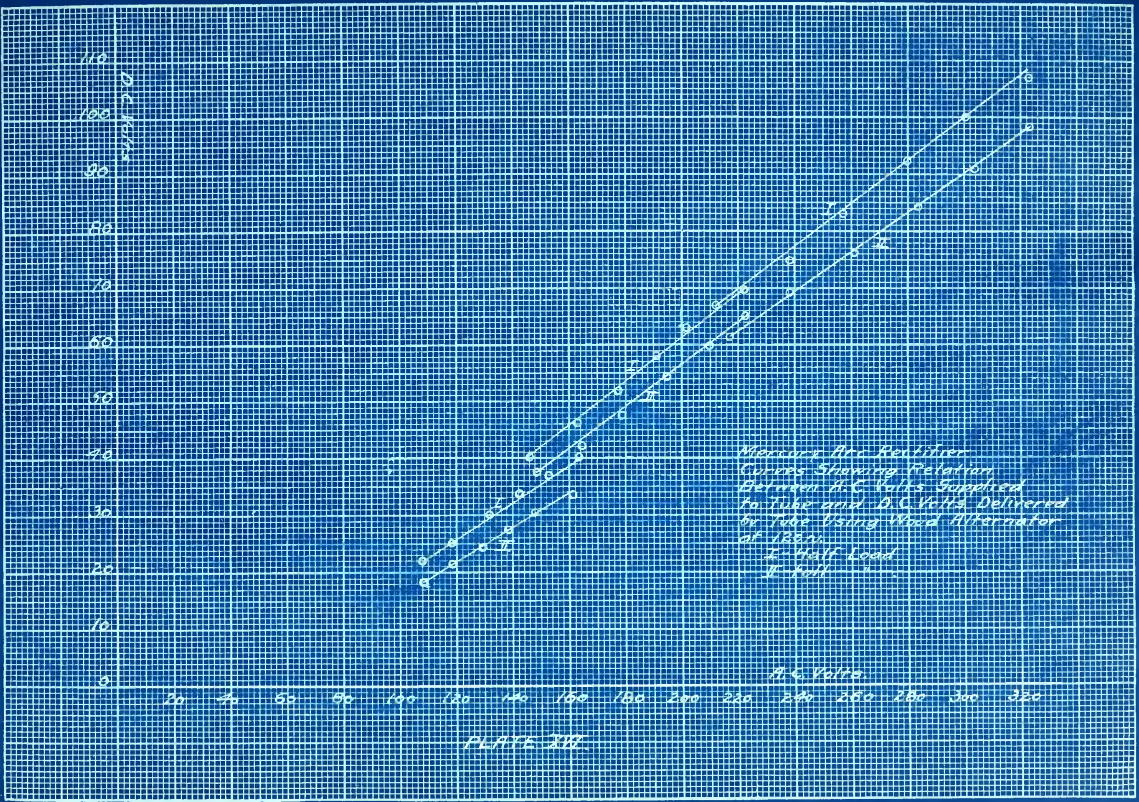
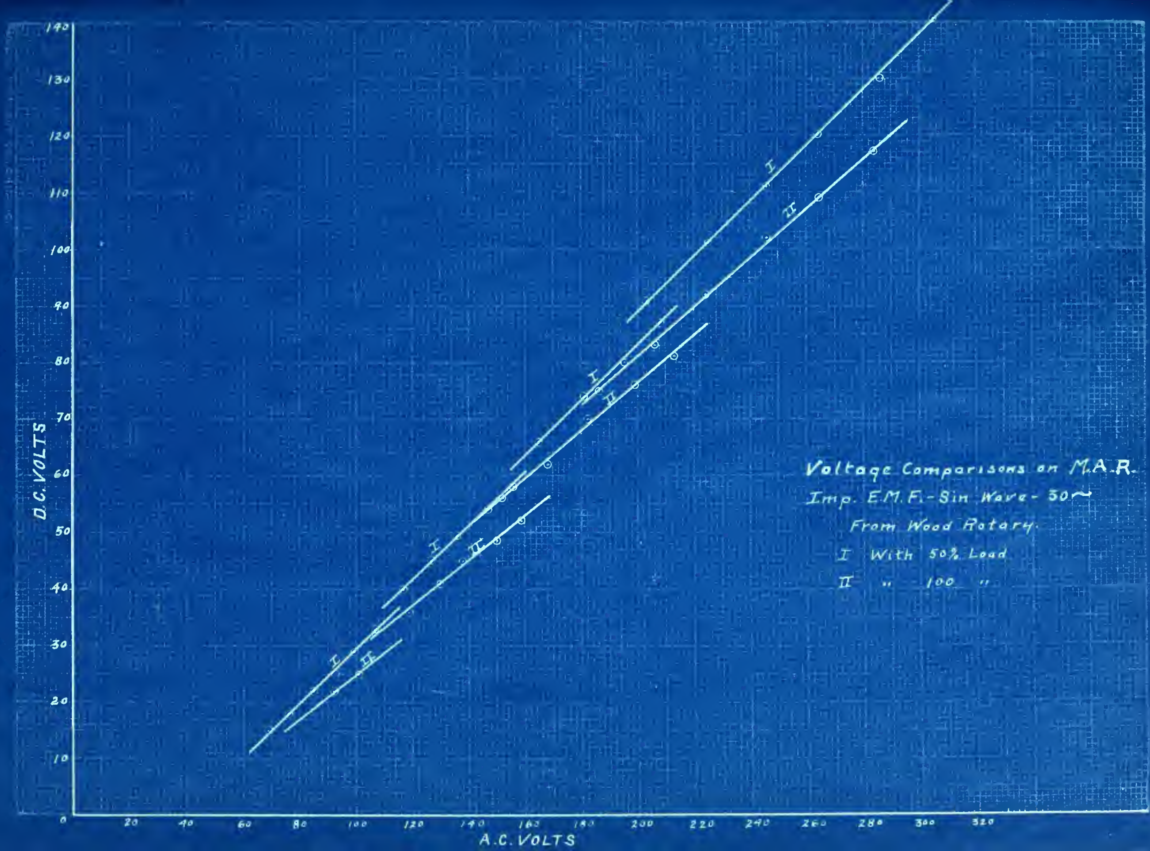
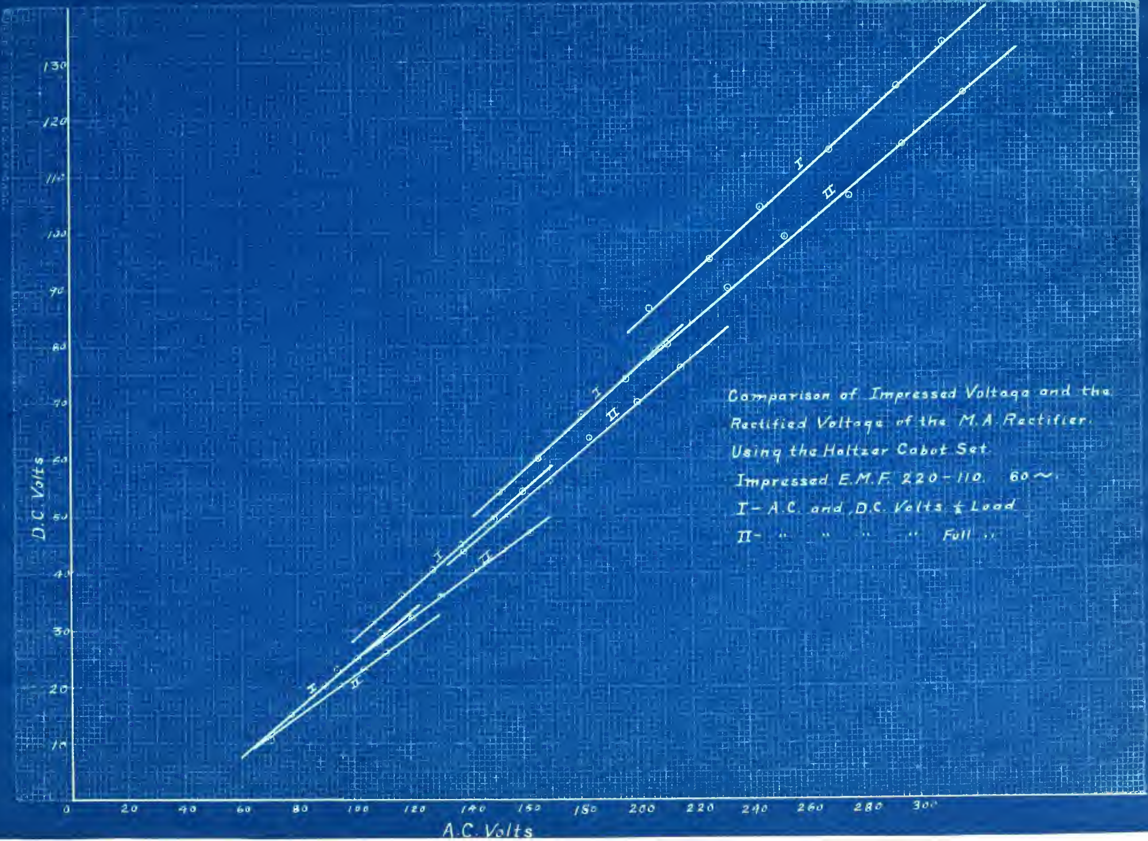

Mercury Arc Rectifier
Curves Showing Relation
Between A.C. Volts Supplied
to Tube and D.C. Volts Delivered
by Tube Using Wood Alternator
at 13 Amp.
I - Half Load
II - Full "
D.C. Volts
A.C. Volts
110
100
90
80
70
60
50
40
30
20
10
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
I
II

PLATE XII


Voltage Comparisons on M.A.R.
Imp. E.M.F. - Sin Wave - 50~
From Wood Rotary.
I With 50% Load
II " 100 "
D.C. VOLTS
A.C. VOLTS
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
I
II


Comparison of Impressed Voltage and the
Rectified Voltage of the M.A. Rectifier.
Using the Holtzer Cabot Set.
Impressed E.M.F. 220 - 110. 60 ~.
I - A.C. and D.C. Volts ½ Load
II - " " " " Full "
D.C. Volts
A.C. Volts
I
II

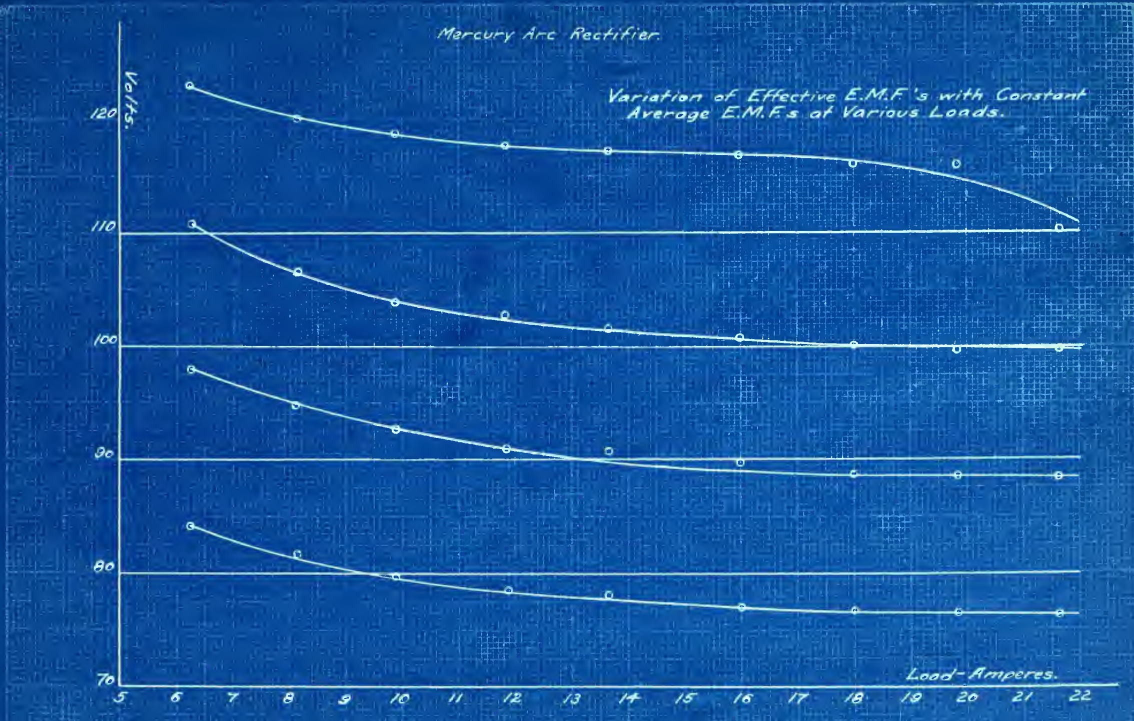

Mercury Arc Rectifier.
Variation of Effective E.M.F.'s with Constant Average E.M.F.s at Various Loads.
Volts.
120
110
100
90
80
70
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Load-Amperes.

PLATE XIX.

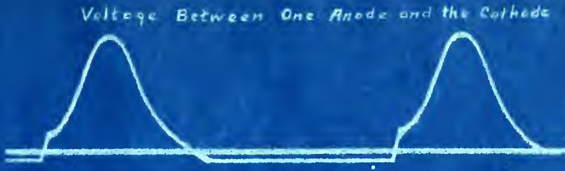


Fig. 1

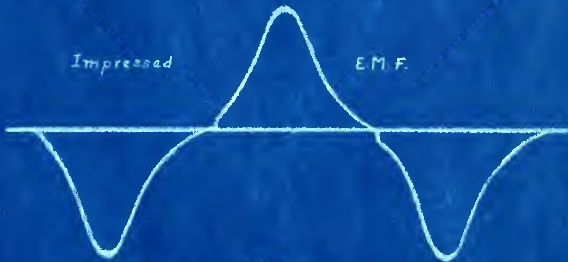


Fig. 2

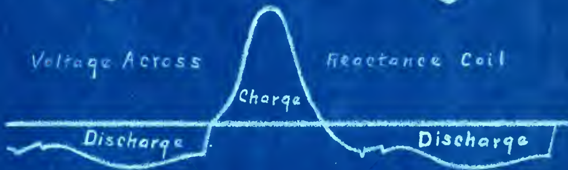


Fig. 3

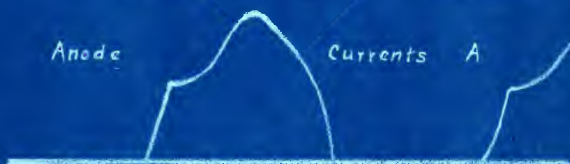


Fig. 4

Plate V. Fig. 2.

Fig. 5

PLATE XX

WAVES FROM THE OSCILLOGRAPH SHOWING TRUE RELATIONS

PLATE XXI

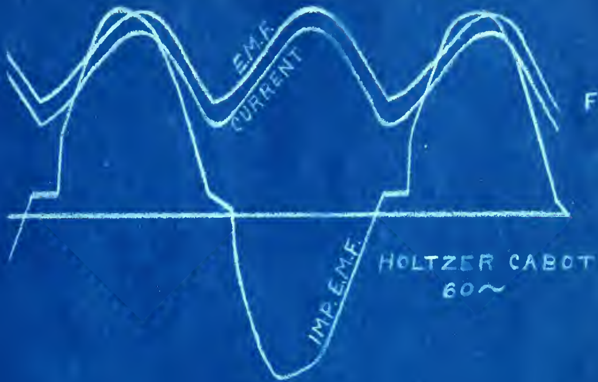


Fig. 1

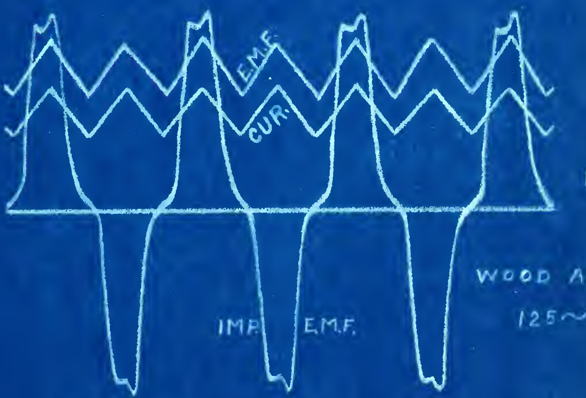


Fig. 2

RECTIFIED E.M.F. AND CURRENTS SHOWING RELATION OF IMPRESSED E.M.F.

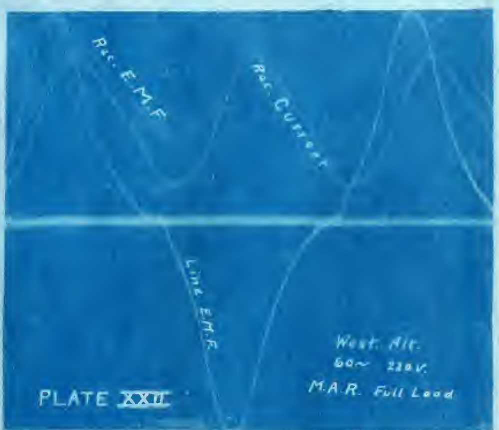


PLATE XXII

PLATE XXIII.

—CONNECTIONS FOR MERCURY ARC RECTIFIER AUTOMOBILE CHARGING PANEL.—

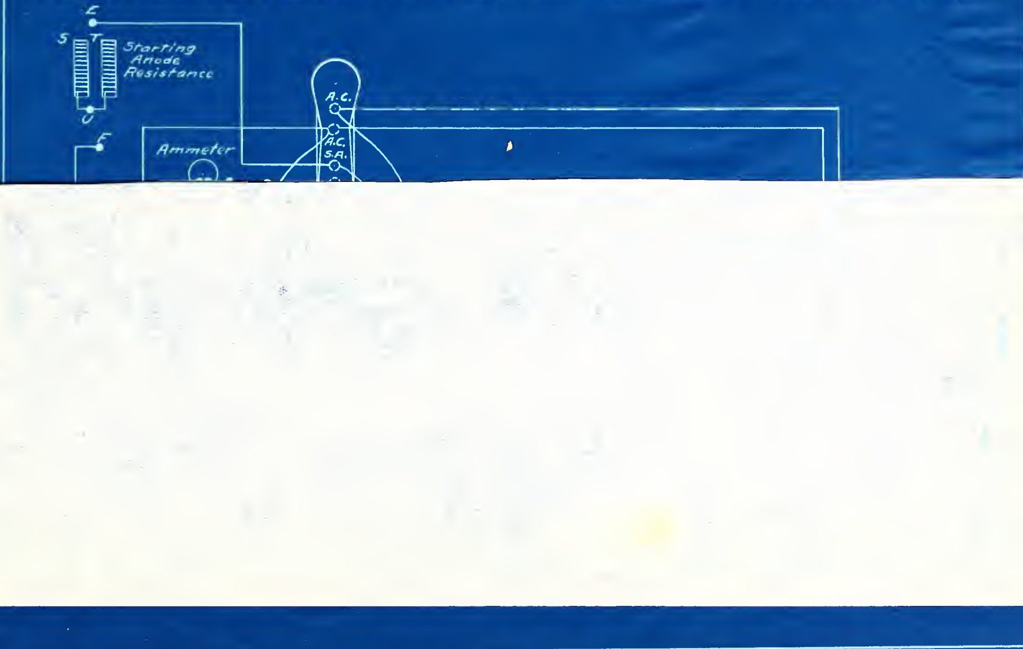
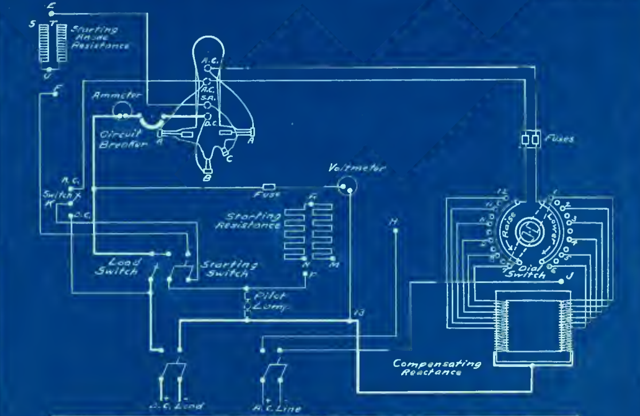


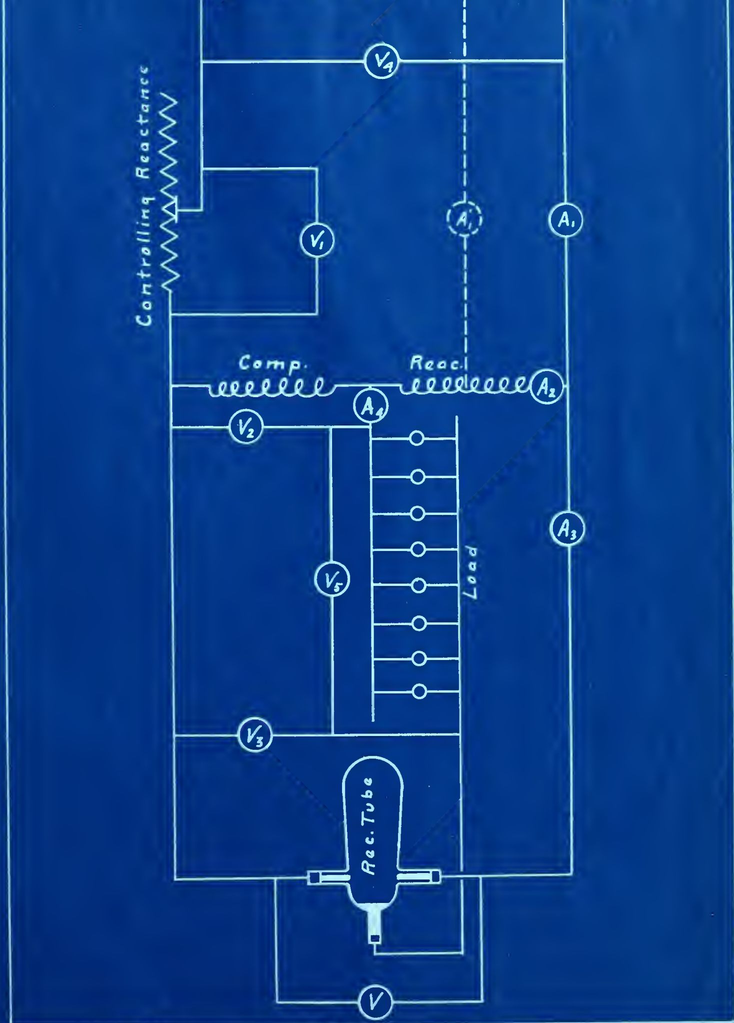
PLATE XXIII.

—CONNECTIONS FOR MERCURY ARC RECTIFIER AUTOMOBILE CHARGING PANEL.—



Connections Starting Anode Resistance.	For 80 to 120 Volts D.C. Connect	E to S and F to T.
	" 46 " 79 " " "	E " S " F " U.
	" 16 " 46 " " "	E " ST " F " U.
Connections Starting Resistance.	For 80 to 120 Volts D.C. Connect	P to N and 13 to M.
	" 46 " 79 " " "	P " N " 13 " R.
	" 16 " 46 " " "	P " MN " 13 " R.
Connections A.C. Line. 220V.	For 80 to 120 Volts D.C. Connect	J to 6 and H to 12.
	" 46 " 79 " " "	J " 1 " H " 7.
110V.	For 30 to 46 Volts D.C. Connect	J to 6 and H to 12.
	" 16 " 30 " " "	J " 1 " H " 7.

PLATE XXIV



V_4
Controlling Reactance
A_1
A_1
V_1
Comp.
Reac.
A_2
A_4
V_2
A_3
V_5
Load
V_3
Rec. Tube
V

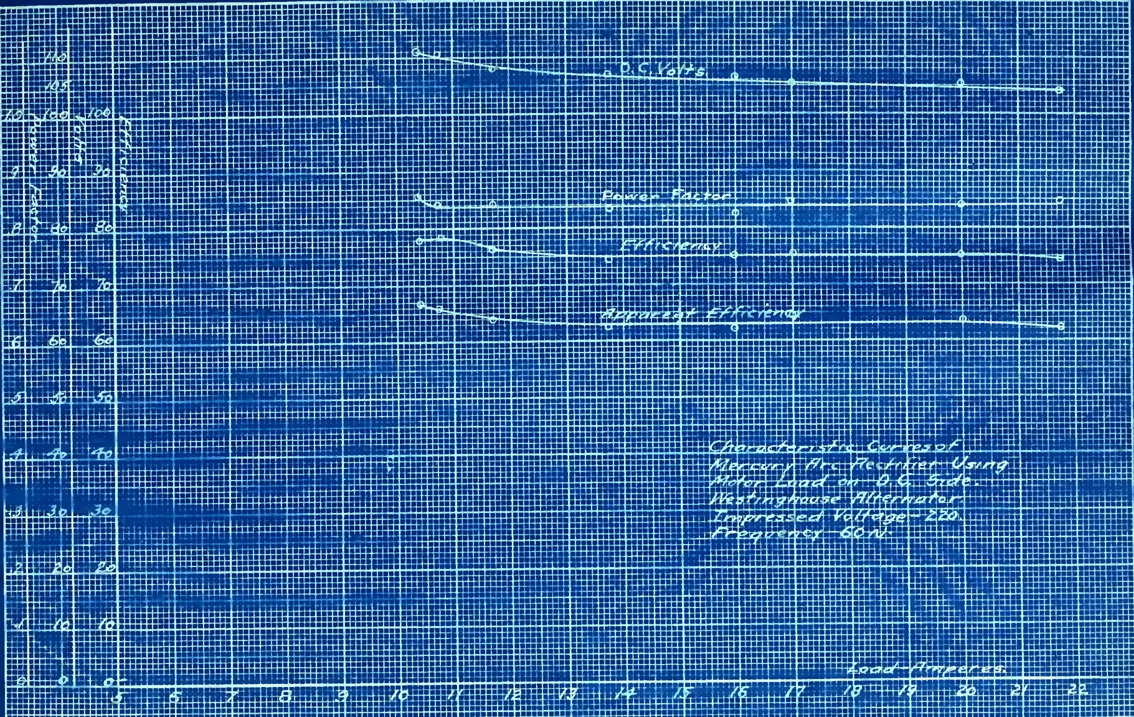

D.C. Volts
Power Factor
Efficiency
Apparent Efficiency
Characteristic Curves of
Mercury Arc Rectifier Using
Motor Load on D.C. Side.
Westinghouse Alternator
Impressed Voltage 220.
Frequency 60~
Load Amperes.
Power Factor
Volts
Efficiency
0
1
2
3
4
5
6
7
8
9
1.0
10
20
30
40
50
60
70
80
90
100
105
110
11
12
13
14
15
16
17
18
19
20
21
22

PLATE XXV

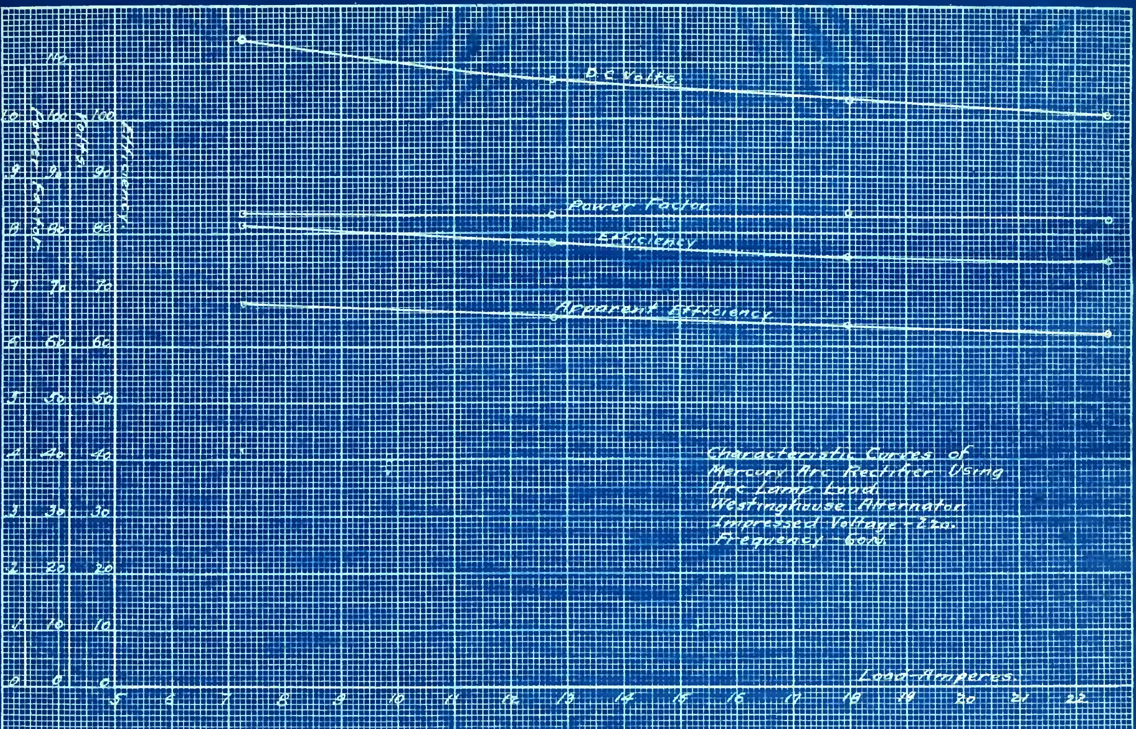

D.C. Volts.
Power Factor.
Efficiency
Apparent Efficiency
Characteristic Curves of
Mercury Arc Rectifier Using
Arc Lamp Load
Westinghouse Alternator
Impressed Voltage - 220.
Frequency - 60N.
Load Amperes.
Power Factor.
Volts.
Efficiency.

PLATE XXVI.

DISCUSSION.

We will devote our attention now to an interpretation of the results as shown by the curves.

We will first compare the results obtained with a peaked wave, at different frequencies using an impressed voltage of 220. From a comparison of Plates VII and VIII we note the following points:--

1. At 120 cycles the efficiency is greater than at 60 cycles.

2. The power factor at 60 cycles averages about 8[illegible]%, at 120 cycles, about 85%.

3. At 60 cycles the D.C. voltage is continually about two volts higher than that at 120 cycles.

Under the same conditions as above but using an impressed voltage of 110 volts, we find from a comparison of Plates XI and XII that:--

1. That the efficiency at 120 cycles is on an average greater than that at 60 cycles.

2. The power factor at 60 cycles averages about 80% and at 120 cycles about 75%.

3. At 60 cycles the D.C. voltage is continually 2 volts higher than that at 120 cycles.

These results are similar to those obtained at 220 volts.

The efficiency is higher at 120 cycles than at 60 cycles owing to the fact that the inductance effect increases with the frequency and makes the rectified characteristics assume more nearly a straight line. At

120 cycles the rectified E.M.F. and current are of lesser amplitude than at 60 cycles and give more nearly a direct current.

We now will compare the results obtained with a sine wave at different frequencies with an impressed voltage of 220. From a comparison of Plates IX and X we note:--

1. At 60 cycles the efficiency is higher than that at 30 cycles at various loads.

2. The power factor at 30 cycles is somewhat higher on the average than that at 30 cycles.

3. The D.C. voltage at 30 cycles is higher than that at 60 cycles.

With 110 impressed voltage on the supply line the same conclusions hold.

Comparing the effect of wave form at the same frequency we find from a comparison of Plates VII and X that :--

1. The efficiency with a sine wave is much greater than with a peaked.

2. The sine wave gives a better power factor.

3. The D.C. voltages are approximately the same.

The same conclusions hold true for both 110 and 220 impressed voltage.

The choice of 220 or 110 voltages depends on the supplying line and the D.C. voltage desired which is essential in the storage battery work.

In general the efficiency curves with peaked waves have a large hump at the lower loads which the effici-

ency curves on sine waves have not.

The mercury arc rectifier works very well on arc lamp load which is shown in Plate XXVI.

The rectifier gives fair results when operating on motor load, but it is difficult to supply a large enough starting current without overloading the rectifier.

Plates XV, XVI, XVII and XVIII show the relation of D.C. volts delivered to A. C. volts supplied to tube.

With the same form of wave the conversion of voltage is about the same, as can be seen from the plates.

With a sine wave a greater D.C. voltage can be obtained for the same A.C. voltage supplied, than with a peaked wave.

Plate XIX shows the relation of the effective E.M.F. and constant average E.M.F. at various loads. These voltages were measured respectively with an A.C. voltmeter and a D.C. voltmeter across the same points. The average E.M.F. was maintained constant by slightly altering the line E.M.F. and the corresponding effective reading taken. As the load increased the armature reaction of the alternator caused a change in the shape of the impressed wave form that produced a corresponding change on the D.C. wave which caused a variation of effective E.M.F.

ADVANTAGES AND DISADVANTAGES.

The mercury arc rectifier is self-contained, requiring only to be connected to the secondaries of the supply transformer and to the load. The panel completely equipped requires a floor space of approximately 18 inches by 18 inches and has a height of 76 inches. If supported by a wall, the floor space may be further reduced. On the panel is mounted a voltmeter and ammeter, circuit breaker and fuses and all the necessary switches for operating the rectifier.

The first cost of the mercury arc rectifier is comparatively low, the 20 ampere capacity being about $225.00.

As the loss in the arc is constant the efficiency of course varies with the D.C. voltage delivered. The efficiency holds up very high down to one quarter load, averaging from 75 to 95 per cent, which is not true in motor generator sets. The average test on an electrolytic rectifier gives an efficiency of about 65 per cent. With a motor generator of similar capacity the efficiency would be about 55 per cent over the whole run.

Under ordinary conditions of test the power factor averaged approximately 90 per cent. It is of special interest to know that this high power factor is practically maintained in charging, whether a low or a high voltage battery is being charged.

The mercury arc rectifier is especially adapted to charging storage batteries on account of the inherent regulation.

As the voltage of the charging batteries comes up the current ~~circuit~~ required is less and this permits the rectifier to impress a higher direct current E.M.F. which is required to overcome the E.M.F. of the cells. If a motor generator set stops while charging the accumulator is short circuited through the armature of the generator, seriously injuring the cells and probably burning out the armature. Under similar conditions the mercury arc rectifier does no damage to the cells nor in any way affects itself when the arc is broken on account of the load or a shutdown in the line. The breaking of the arc opens the circuit, thus protecting both battery and rectifier and using absolutely no power from the line.

The mercury arc rectifier is unique in that it has no moving parts. There is no danger of fire from over-heated journals and sparking commutators. This rectifier is free from vibrations, oil, dirt and noise which is very disagreeable under certain conditions. On account of its simplicity the mercury arc rectifier can be installed and operated by unskilled labor. It is more flexible and reliable in operation than other forms of rectifiers. It can be used on any commercial frequency and almost any line voltage giving a wide range of direct current voltage. The entire E.M.F. wave is used which is not true of the electrolytic rectifier.

The disadvantages of the mercury arc rectifier will now be taken up briefly. The only part of the rectifier set that can require maintenance is the tube. The average

life of the tube under normal operating conditions is at least 700 hours. The cost of renewal is merely nominal compared to the numerous advantages. The life of the tube is limited by breakage and loss of vacuum. These dangers are increased by working the tube above its rated capacity.

The minimum load at which this tube will operate is 4.5 amperes and when the load is taken off by a break in the circuit or intentionally the rectifier must be started beofre there can be a D.C. load because the load current forms the arc in the rectifier tube.

The mercury arc rectifier is limited to small capacity on account of the tube but can be used on high voltage. Mercury arc rectifiers are being built for 25000 volts alternating current and to deliver a constant current of 6.6 amperes. A rectifier giving 2000 volts on the direct current side with a load composed of arc lamps is in regular service on the streets of Schenectady, running a number of "magnetite" arcs in series.

On account of the rectified current being pulsating the rectifier cannot be used for all conditions where a direct current is required. The question of injury to storage batteries has been submitted to a storage battery manufacturer and the reply was that there is no possible harm to batteries in charging with a pulsating current.

The poor regulation would be counted as a disadvantage and would be for some loads but since the mercury arc rectifier is almost entirely used for charging accumulators the regulation is an advantage as explained under the subject of advantages.